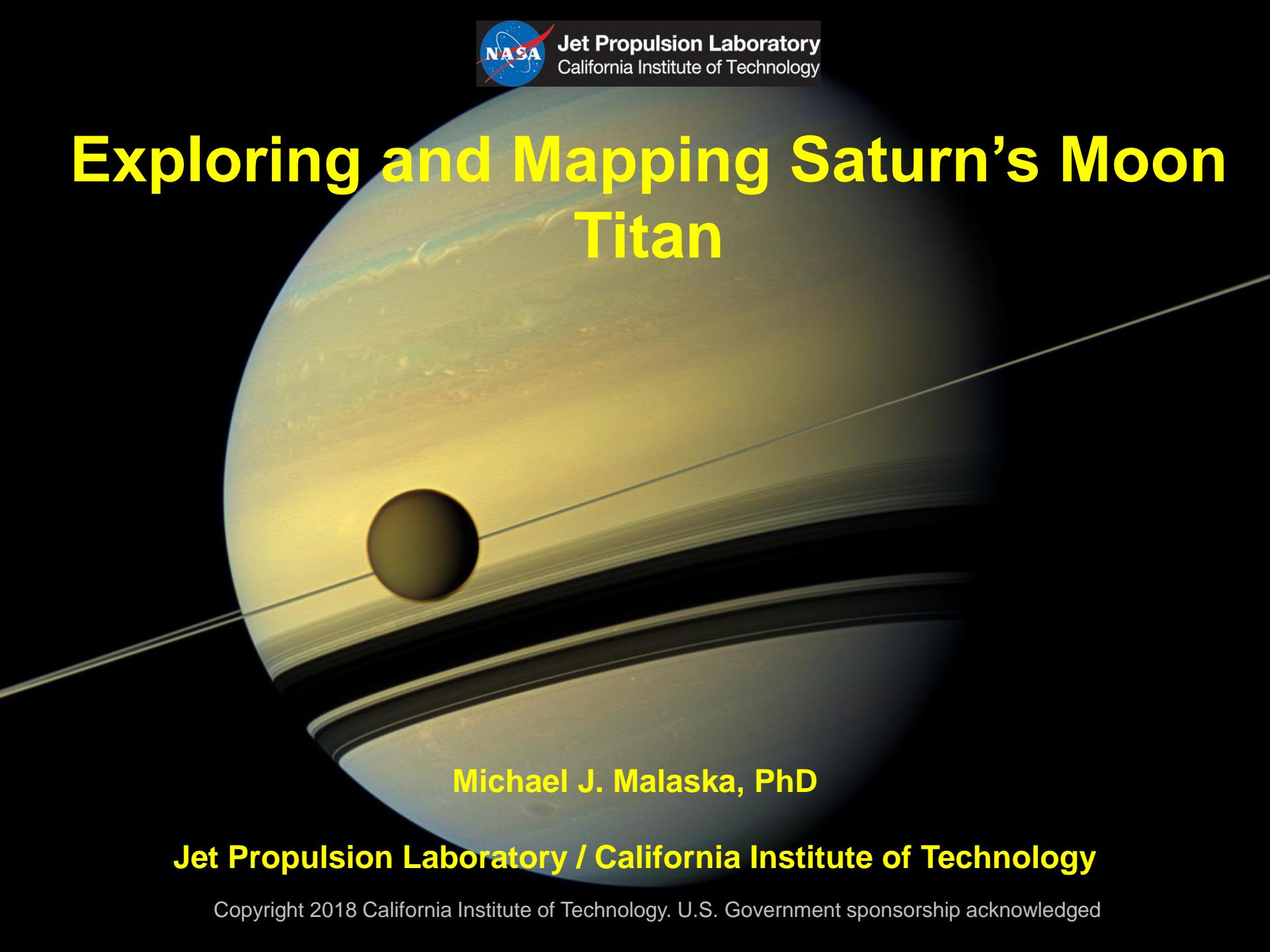


Exploring and Mapping Saturn's Moon Titan

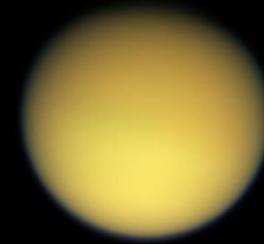


Michael J. Malaska, PhD

Jet Propulsion Laboratory / California Institute of Technology

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Earth vs. Titan



Earth

Titan

Atmosphere
Pressure
Temperature
Liquid cycle
Surface rock
Crustal rock

N_2
1 atm
298 K
 H_2O
 SiO_2 rock
 SiO_2 rock

N_2
1.5 atm
95 K
 CH_4
"Organics"
 H_2O ice

Different temperatures and surface materials

Organic haze obscures Titan's surface



Titan haze layers

Titan's complex organic manifold

More recent models use over 400 equations

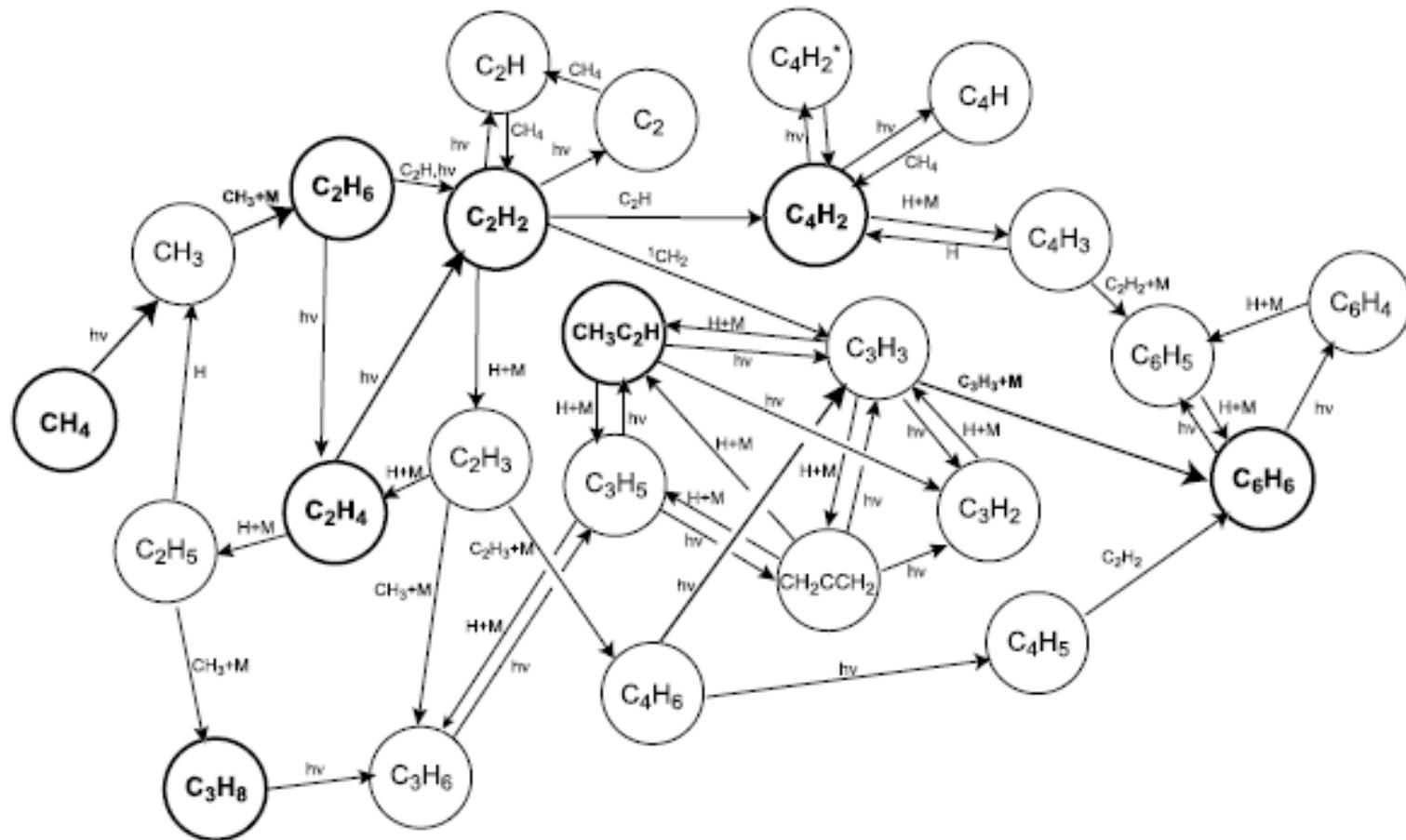


Figure 7 reproduced from:

Wilson and Atreya, J. Geophysical Research 109 (2004) E06002.

Organic chemical fallout

High altitude photochemistry



Monomer production



Radial growth of particulates



Maximum density of monomers

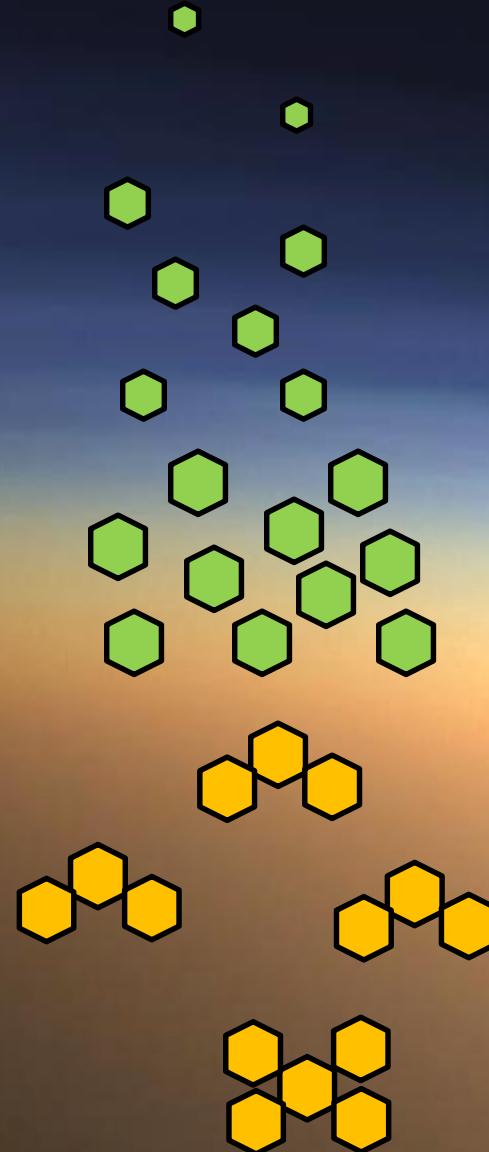


Fractal growth of aggregates

Lower optical density

Builds lower haze layers

Deposit on surface



Solids: Titan's organic molecule surface flux



Krasnopolksy, 2014 model
1 Gyr surface fluxes [1]

75 m total
solids



Components

—75 m Tholin

— 2.6 m C_2H_2

— 2 m HCN

— 1.9 m HCCCN

— 0.2 m CH_3CN

— 0.1 m C_6H_6

Lavvas, 2008 model
1 Gyr surface fluxes [2]

13 m total
solids



Components

— 6 m C_2H_2

— 5 m HCN

— 0.8 m C_2H_4

— 0.5 m CH_3CN

— 0.3 m Tholin

— 0.3 m HCCCN

— 0.2 m C_4H_2

References:

[1] Krasnopoly, V.A., Icarus 201 (2014) 226-256.

[2] Lavvas et al., Planetary and Space Sci. 56 (2008) 67-99.

“Tholin” polymers – the start of it all?



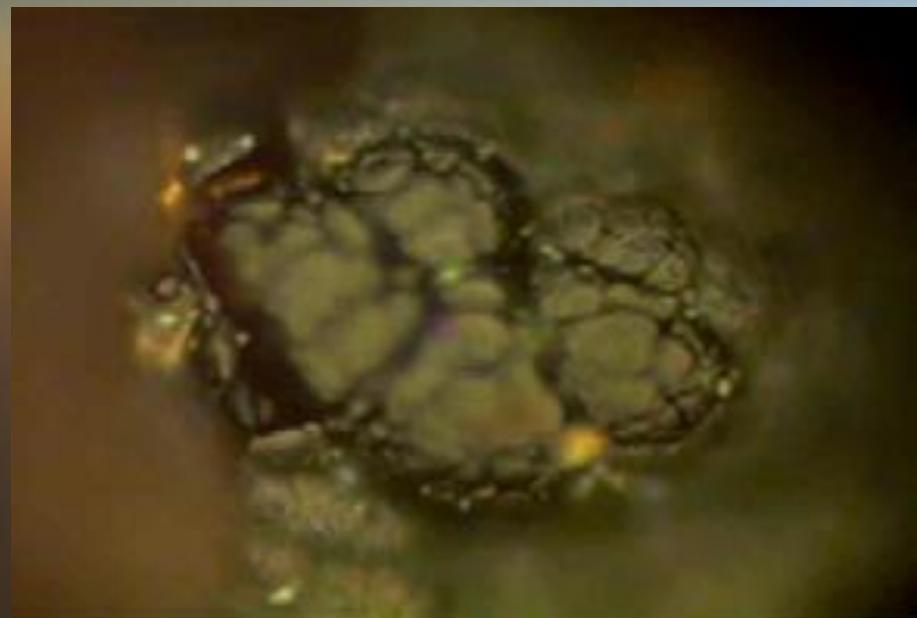
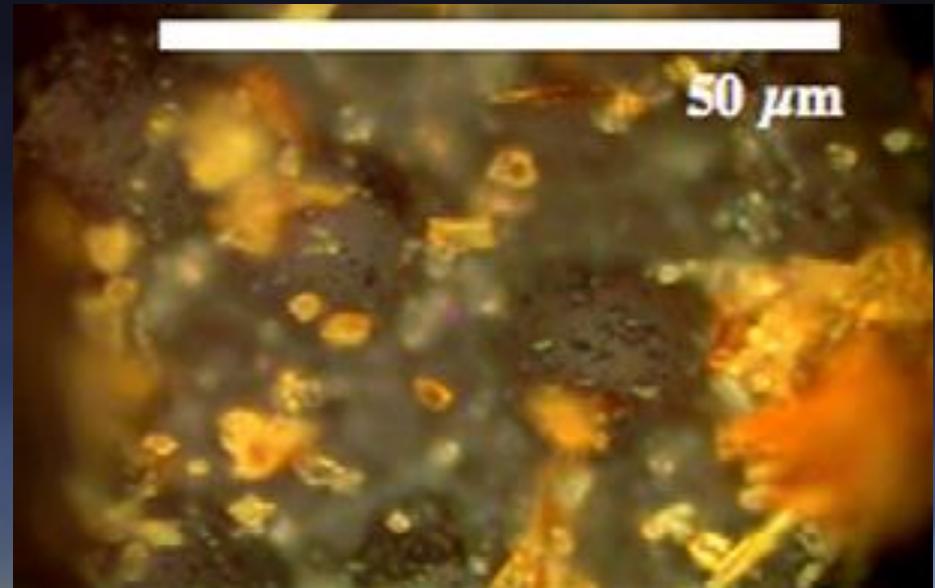
“Tholins”



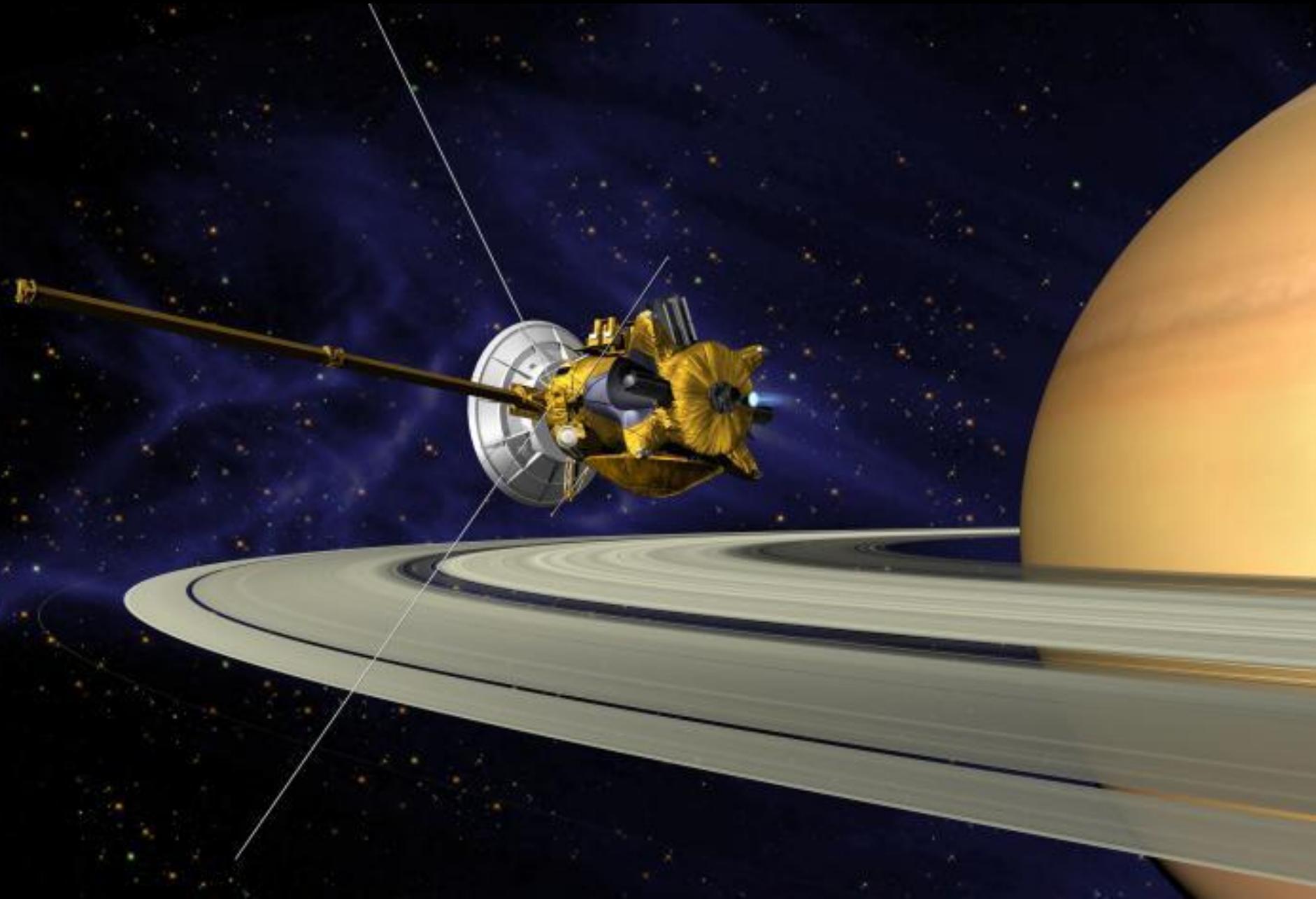
Amino acids



Proteins and enzymes



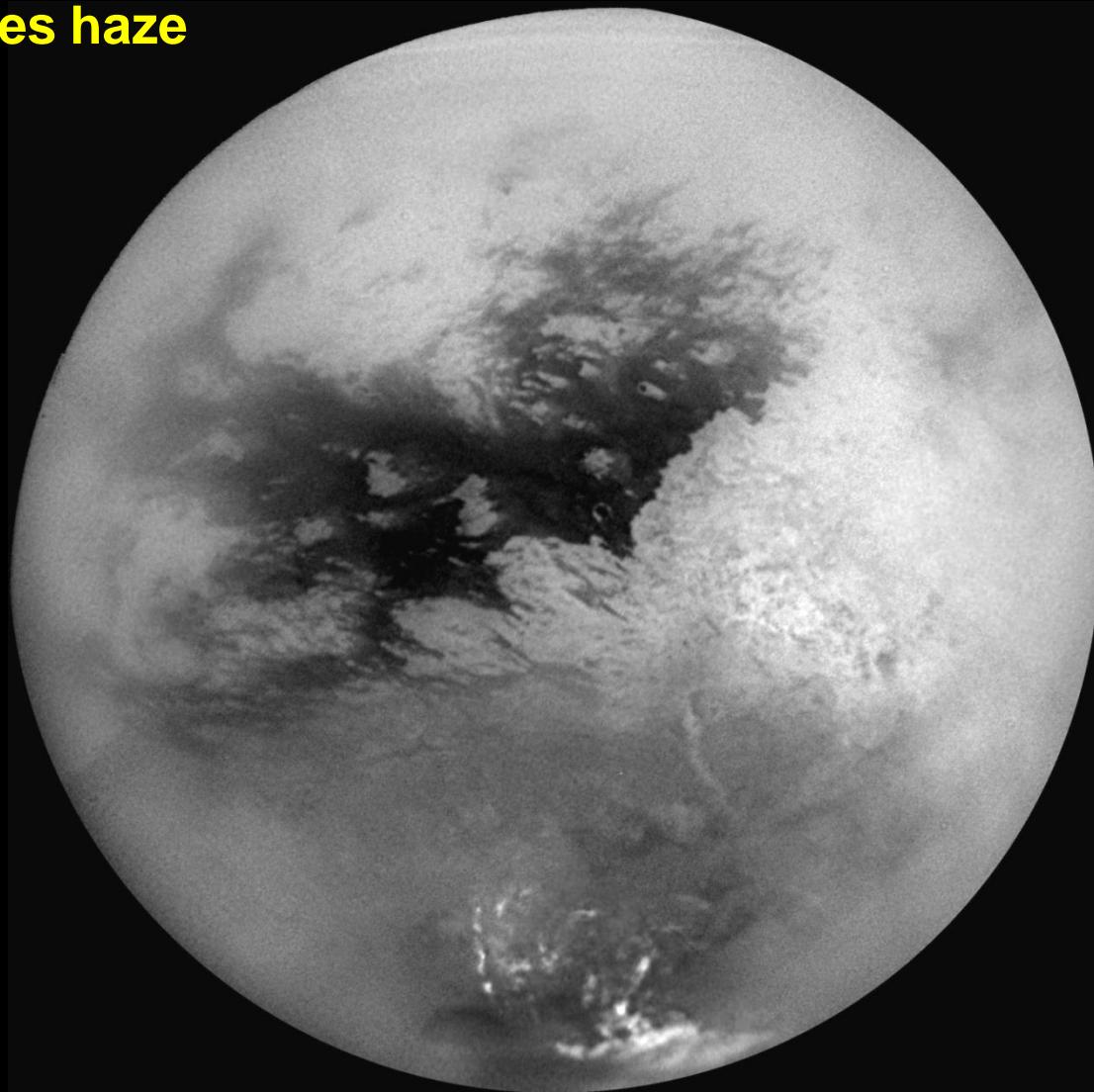
Cassini mission to Saturn



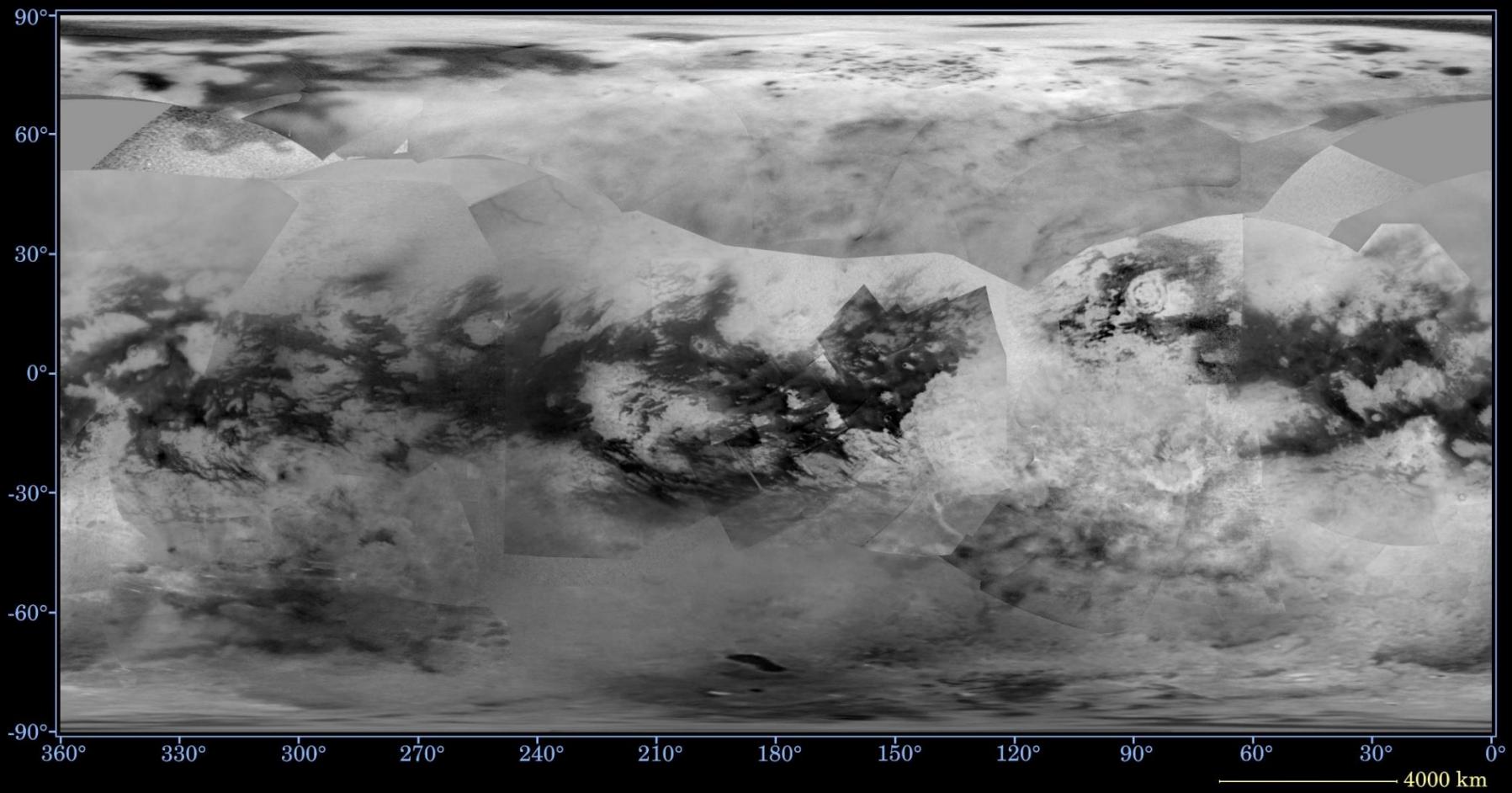
First Cassini view of Titan's surface

IR[0.93 micron] penetrates haze

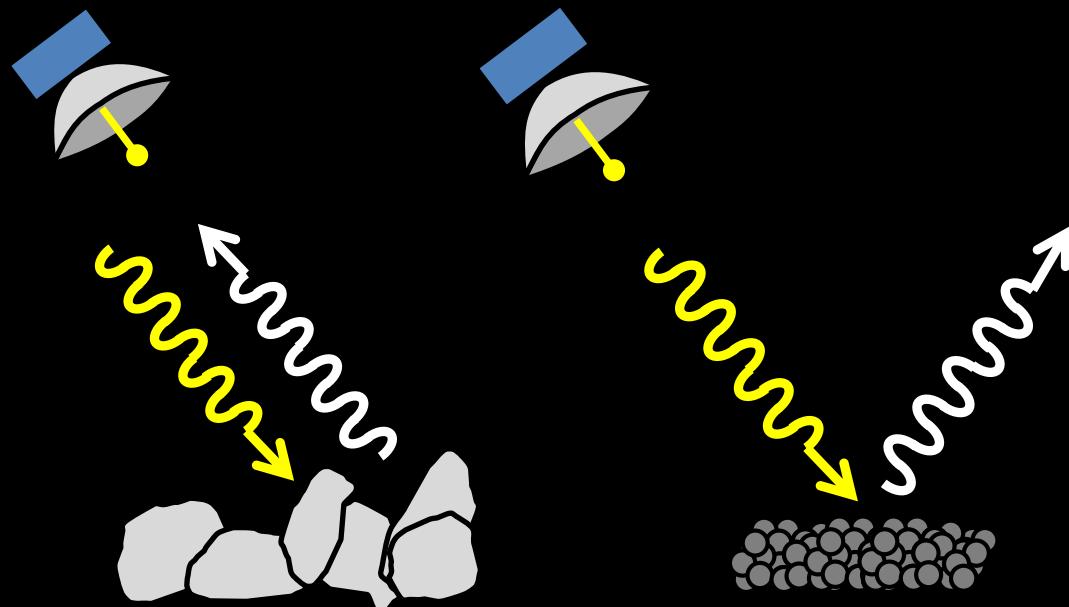
Where are all
the craters?



Titan: IR[0.93 μm] image mosaic



Cassini RADAR[2.2 cm] examines surface Synthetic Aperture Radar (SAR) – how it works



Rough surface
high backscatter
SAR bright

Smooth surface
low backscatter
SAR dark

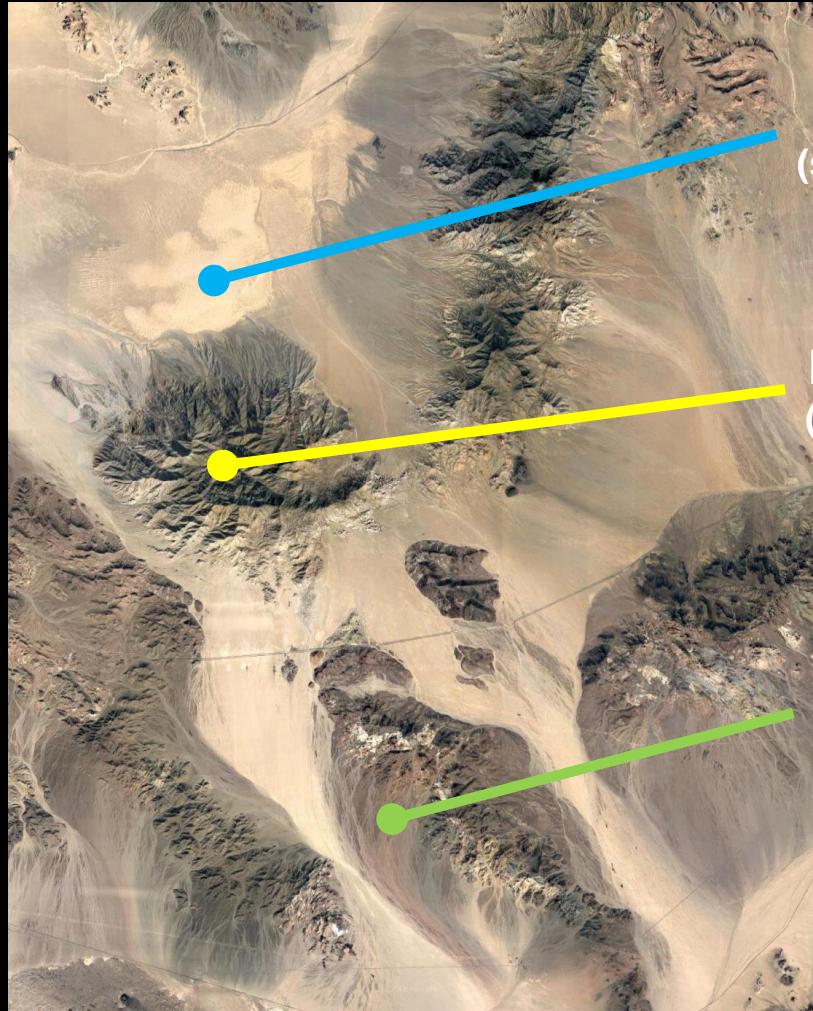
Other factors increase SAR signal:

Incident surfaces
Subsurface layering
Volume scattering
High dielectric materials

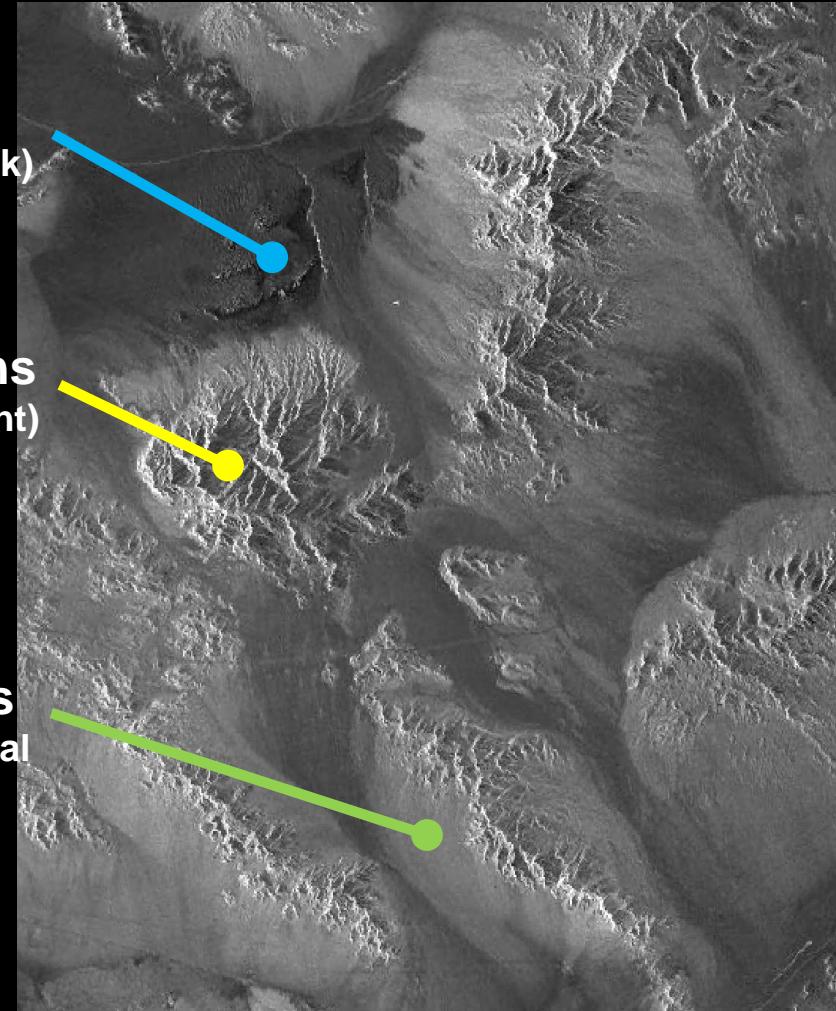
Earth example: Visible and SAR

Kelso Dunes, Mojave desert, CA

Radar illumination direction

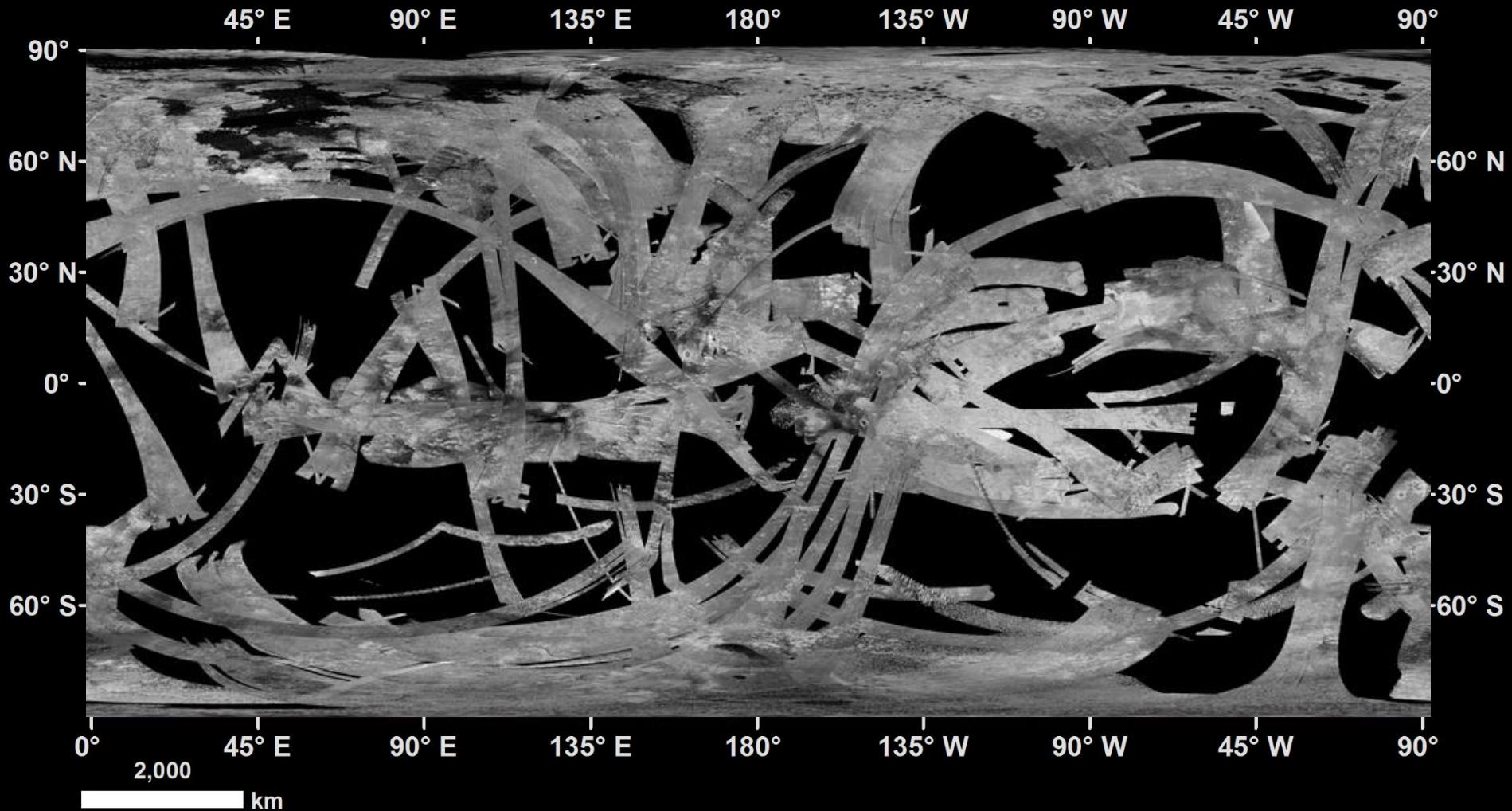


Visible (Google Satellite QGIS layer)



TerraSAR-X

Mapping Titan: SAR strips

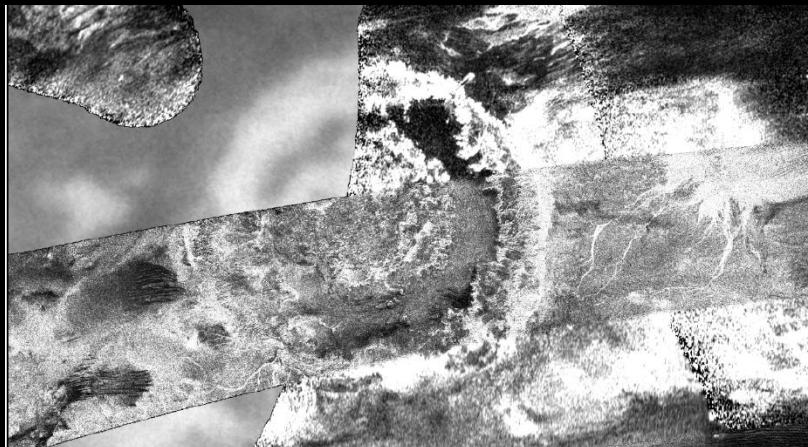


USGS Titan SAR mosaic: https://astropedia.astrogeology.usgs.gov/download/Titan/Cassini/Global-Mosaic/thumbs/Titan_HiSAR_MosaicThru_T104_Jan2015_clon180_128ppd_1024.jpg

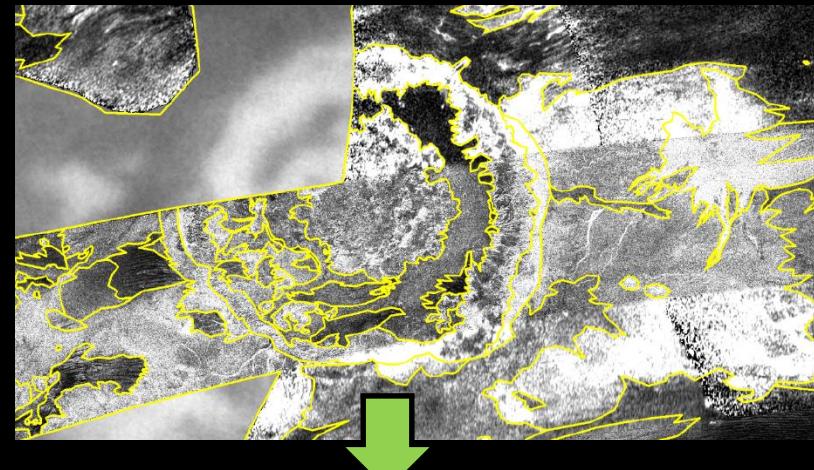
Image credit: USGS

Titan Mapping Technique

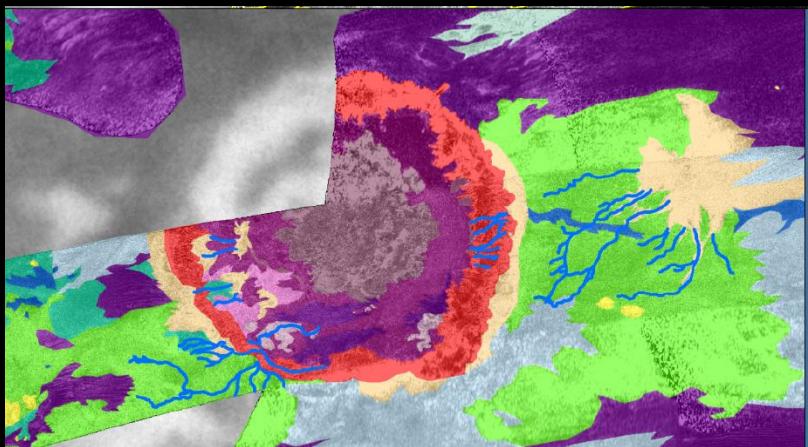
1) Assemble basemap mosaic SAR+IR



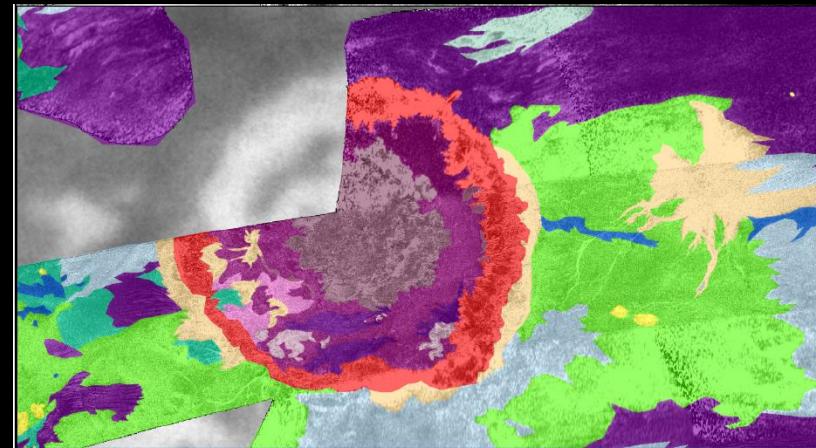
2) Define terrain unit contacts



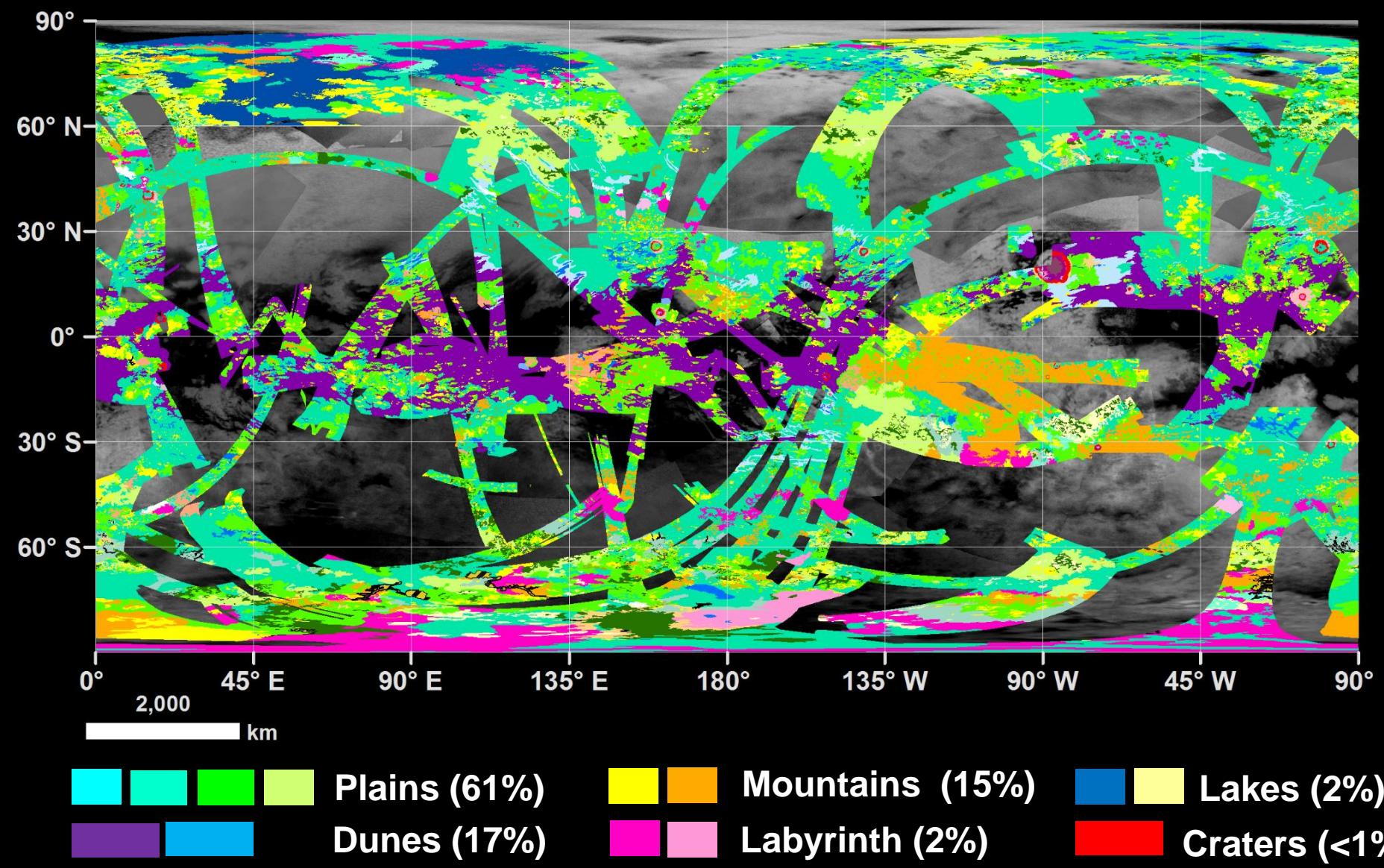
4) Add surface features



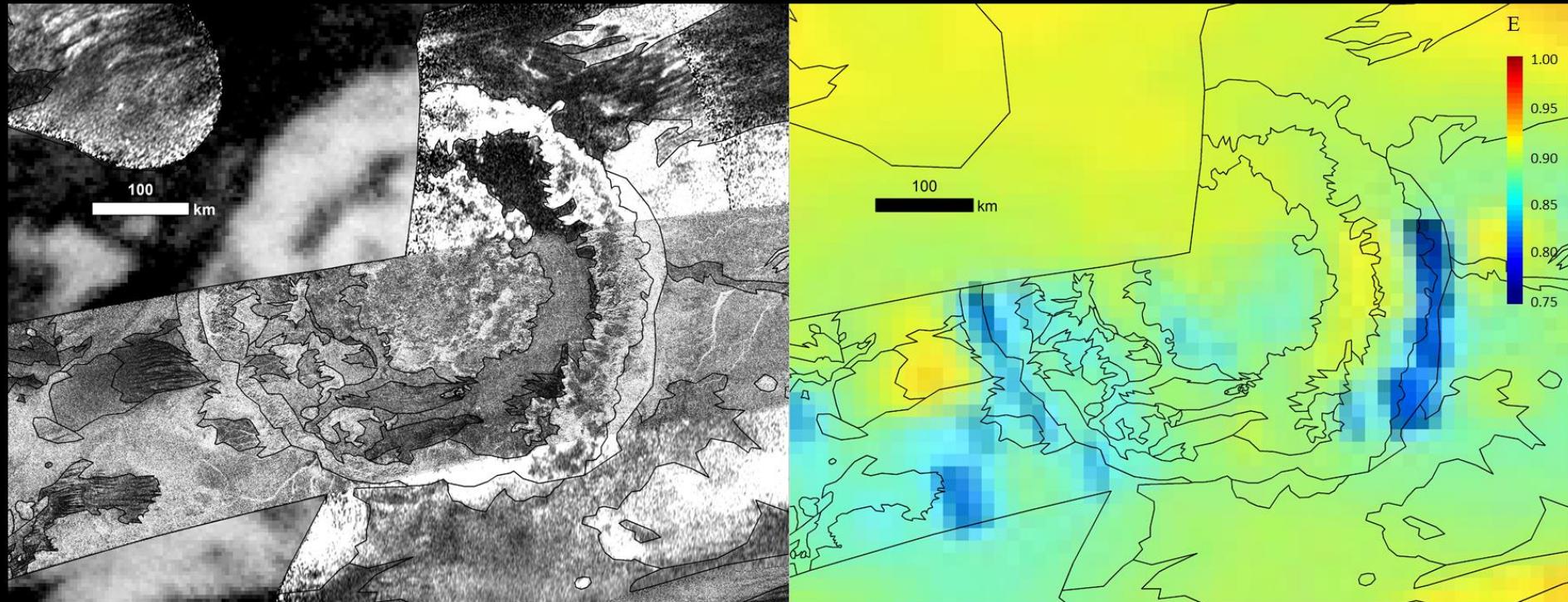
3) Contacts → polygons → classify



Titan terrain units



Microwave Emissivity → Composition

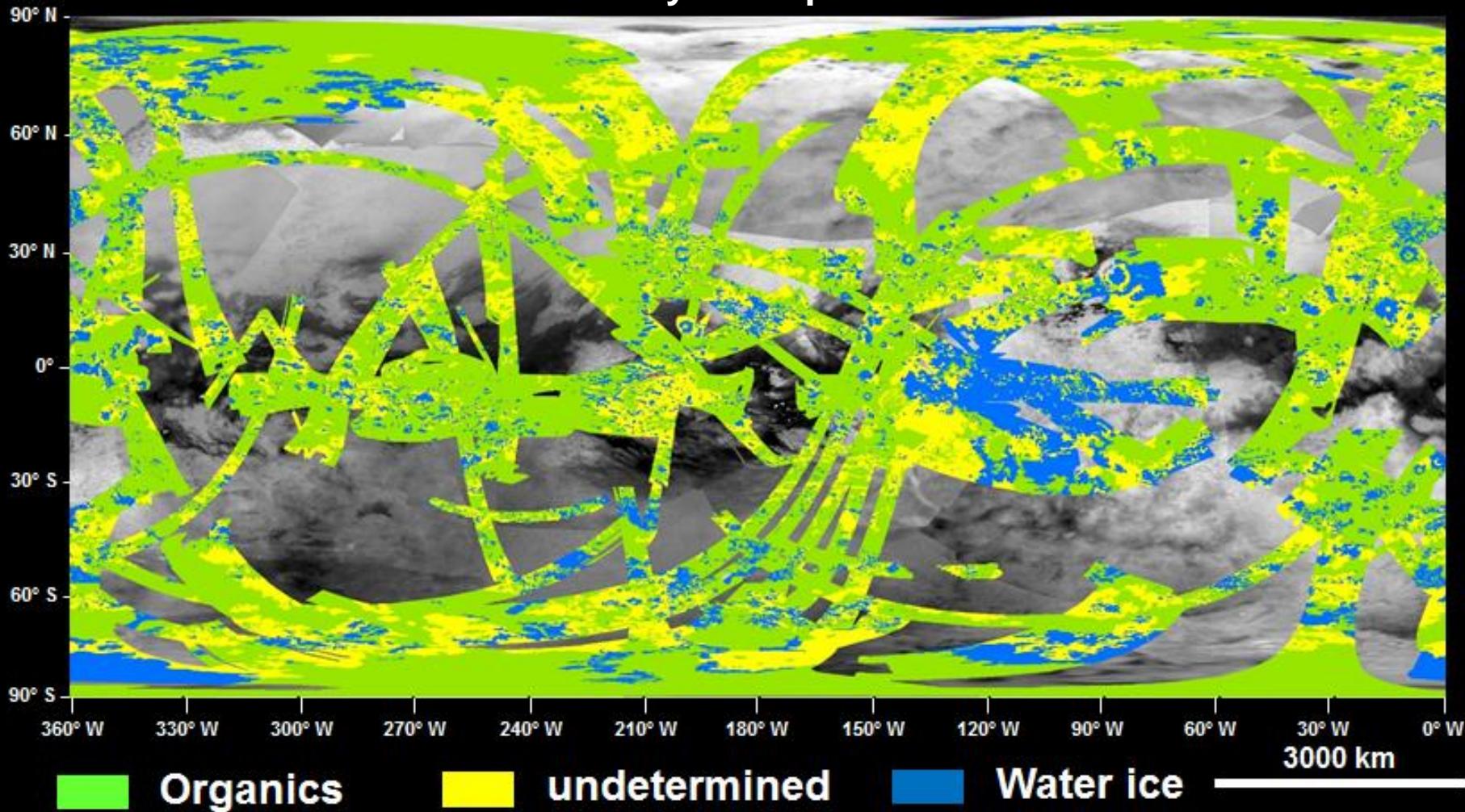


Menrva Crater, 400 km diameter

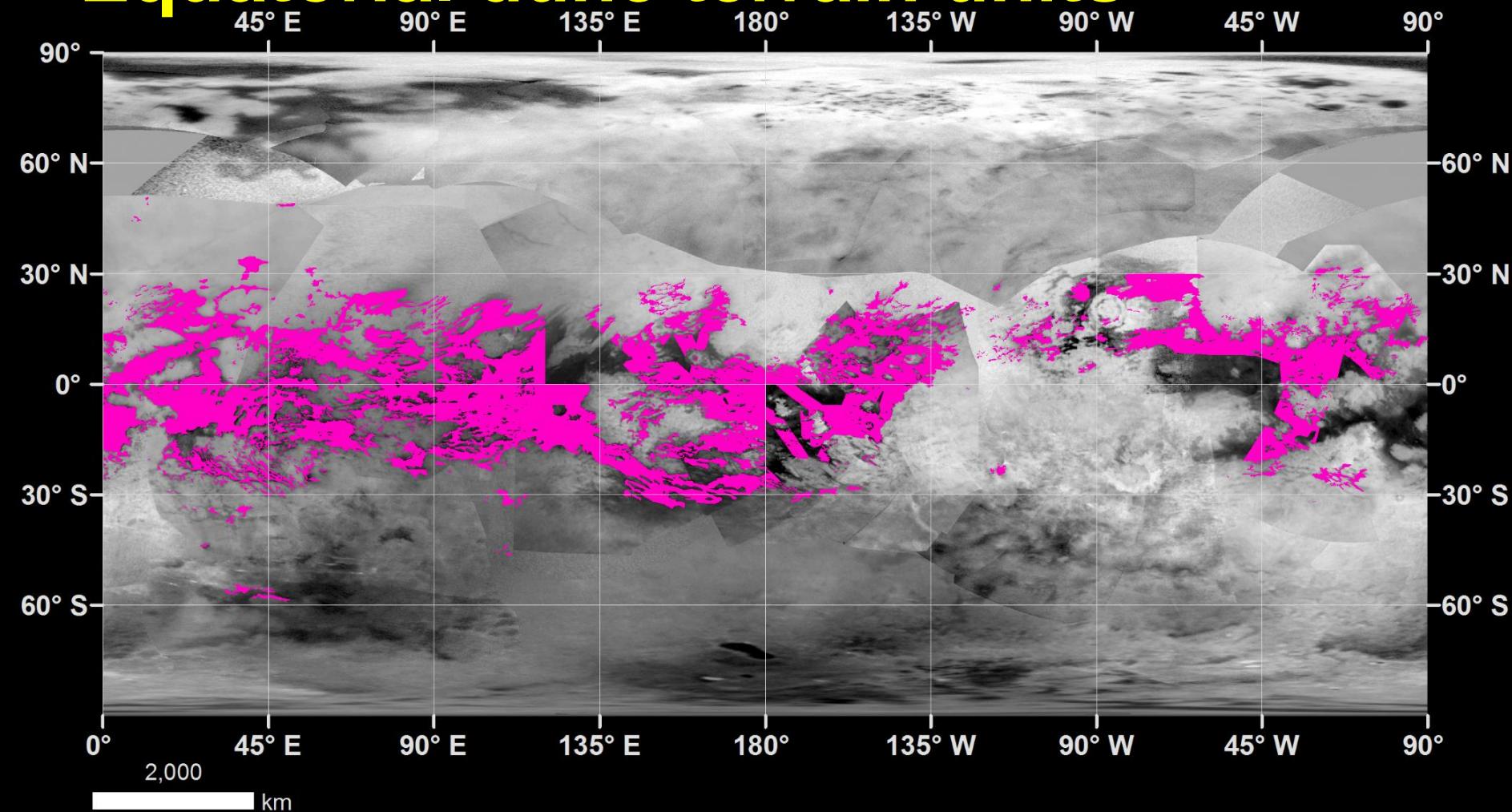
Cold tones → low emissivity (consistent with water ice)
Warm tones → high emissivity (consistent with organics)

Titan surface is mostly organics

Terrain unit microwave emissivity→composition



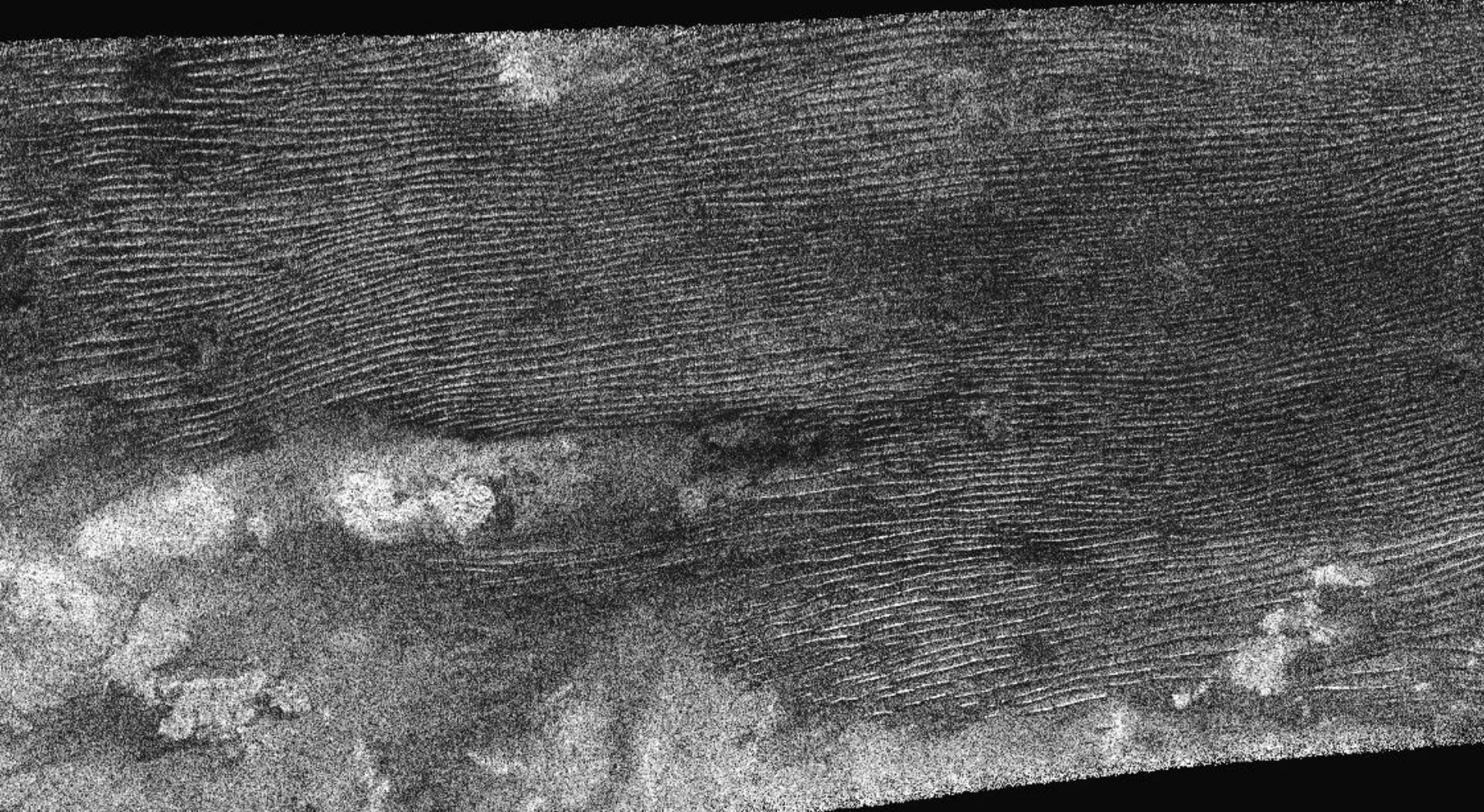
Equatorial dune terrain units



Windswept dunes of organic materials

SAR RADAR image of Belet dune sea

Individual dunes are 100 m high and 100's of km long

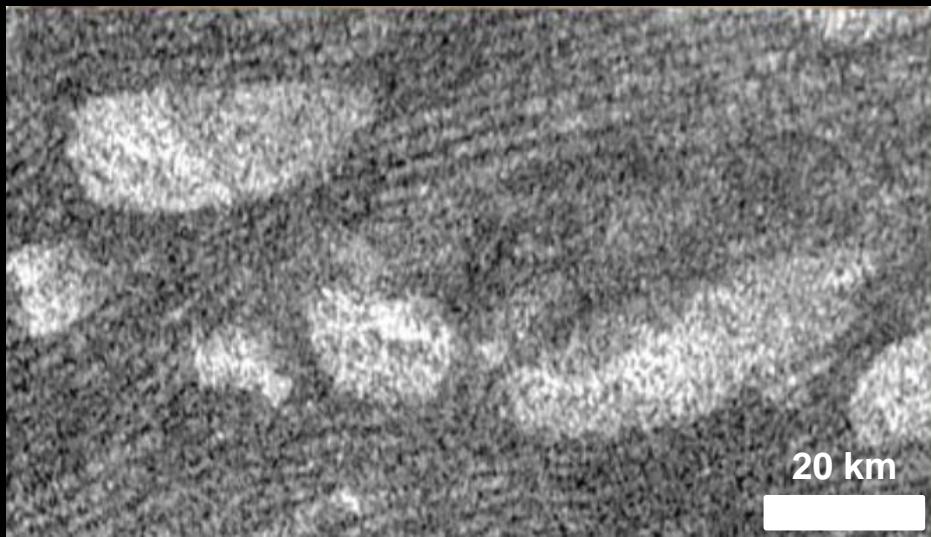


Contrast-adjusted crop from Planetary Photojournal entry PIA08454: <http://photojournal.jpl.nasa.gov/catalog/PIA08454>

Image credits: NASA / JPL

Titan Dunes vs. Earth Dunes

Titan



Belet Sand Sea, Titan

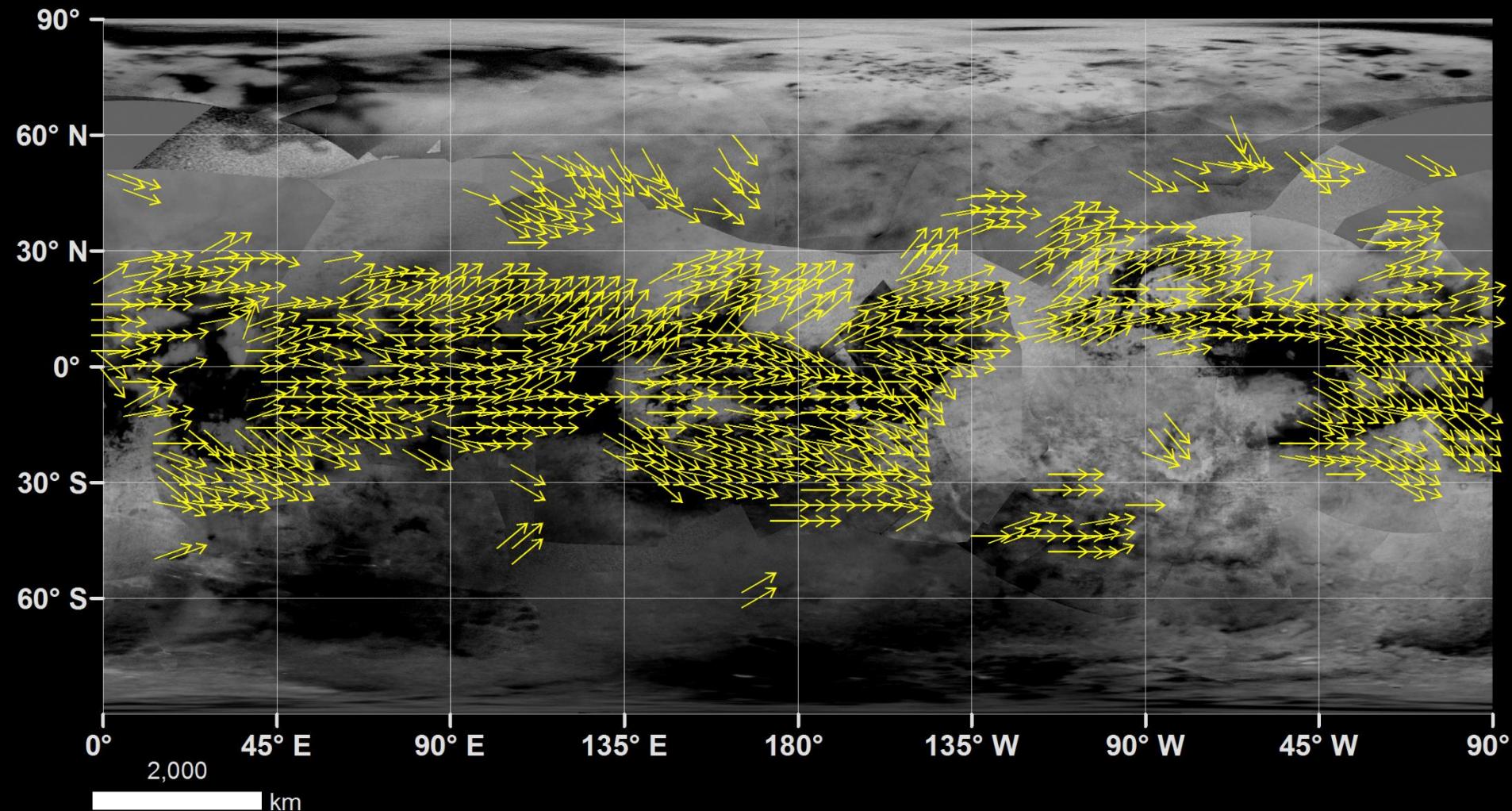
Earth



Egypt, Earth

Dune World Titan

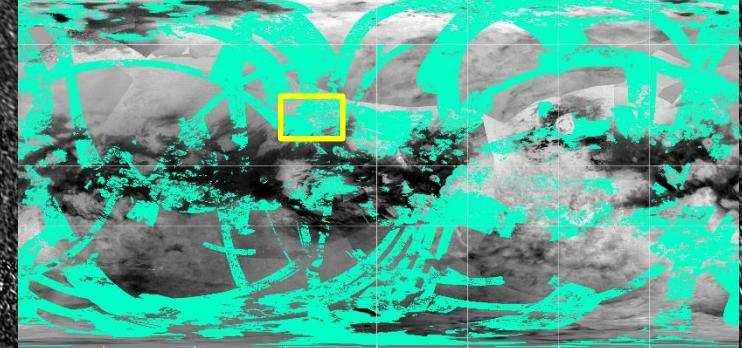
Mapping material transport on Titan Delivery to mid-latitude blandlands



Blandlands

Titan's vast organic plains

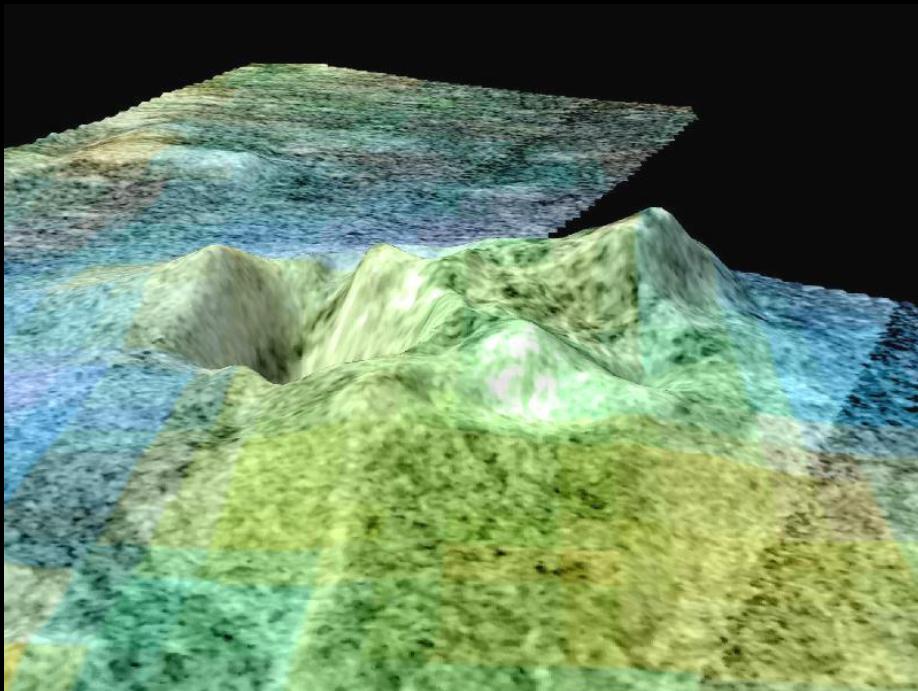
100



“So boring, they are fascinating”

Caladan Planitia,
Titan [20°N, 216°W]

Possible Cryovolcano



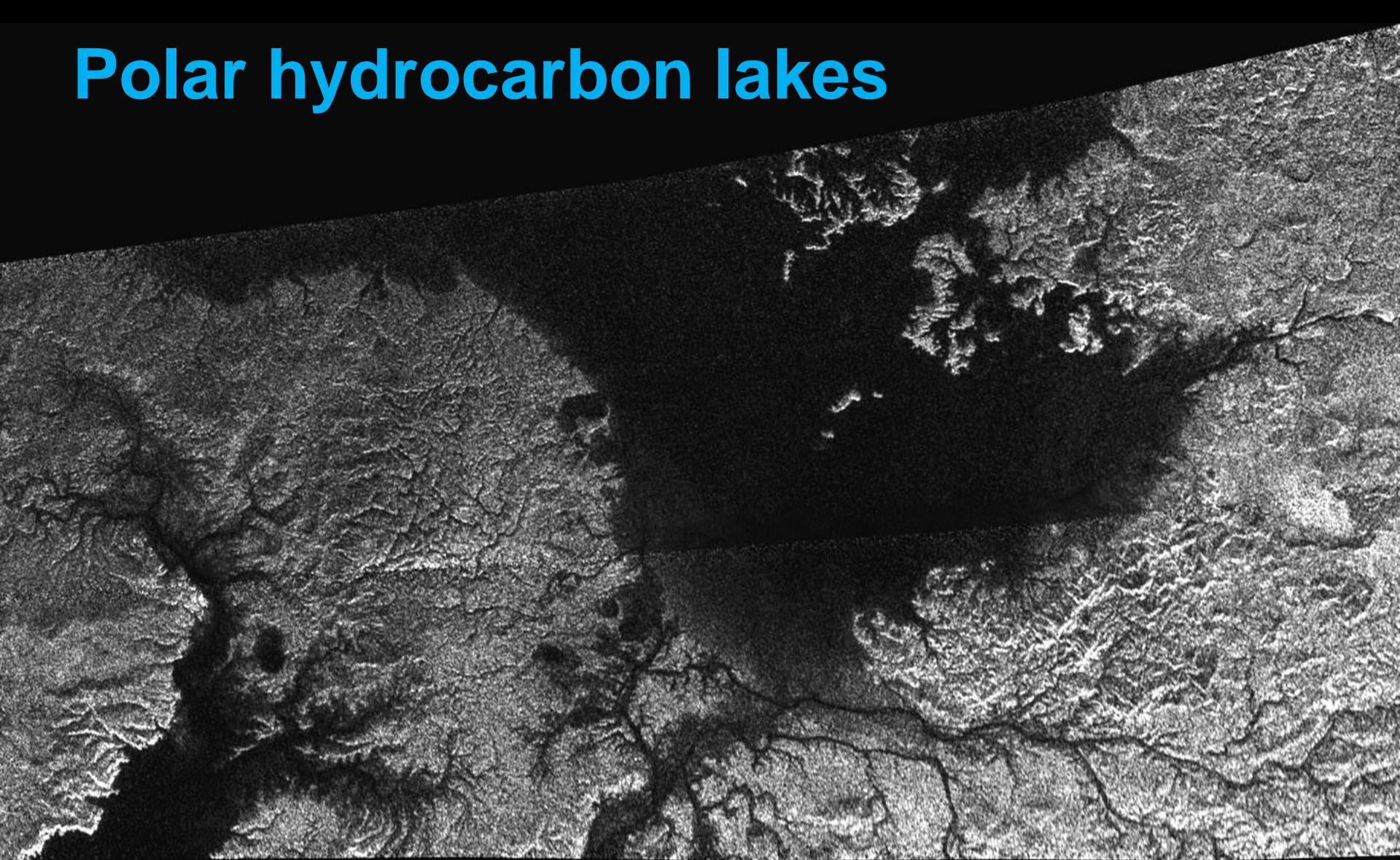
Doom Mons, Aztlan,
3-D stereo RADAR view
Titan [-12.5°S, 39.8°W]



Laki Volcanic Region,
Iceland,
Earth [64.1°N, 18.2°W]

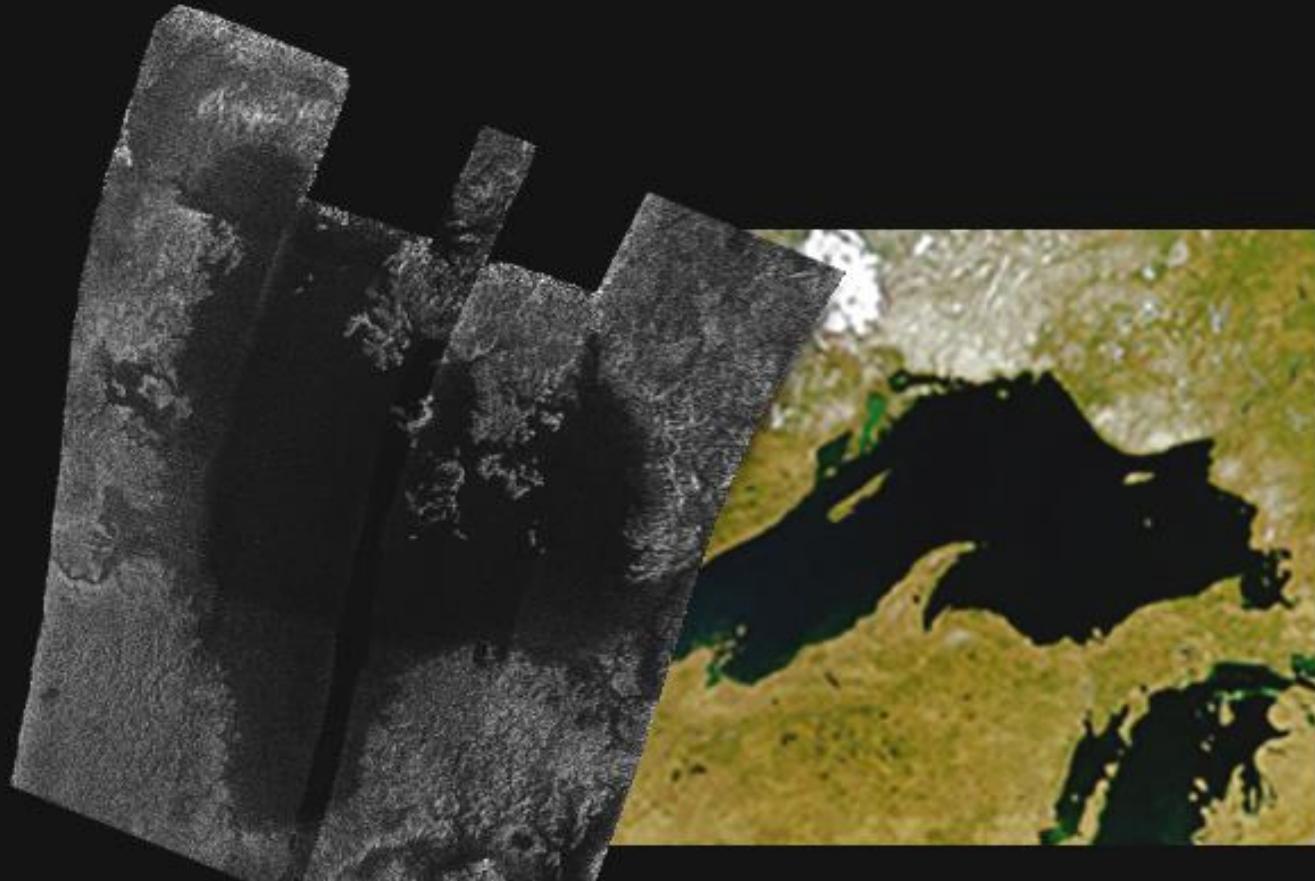
Image credits: Titan: Planetary Photojournal Image PIA 13695: <http://photojournal.jpl.nasa.gov/catalog/PIA13695>
Earth: Rosaly C. Lopes

Polar hydrocarbon lakes



SAR RADAR image of hydrocarbon lakes and channels on Titan

Titan Lakes vs. Earth Lakes: sizes



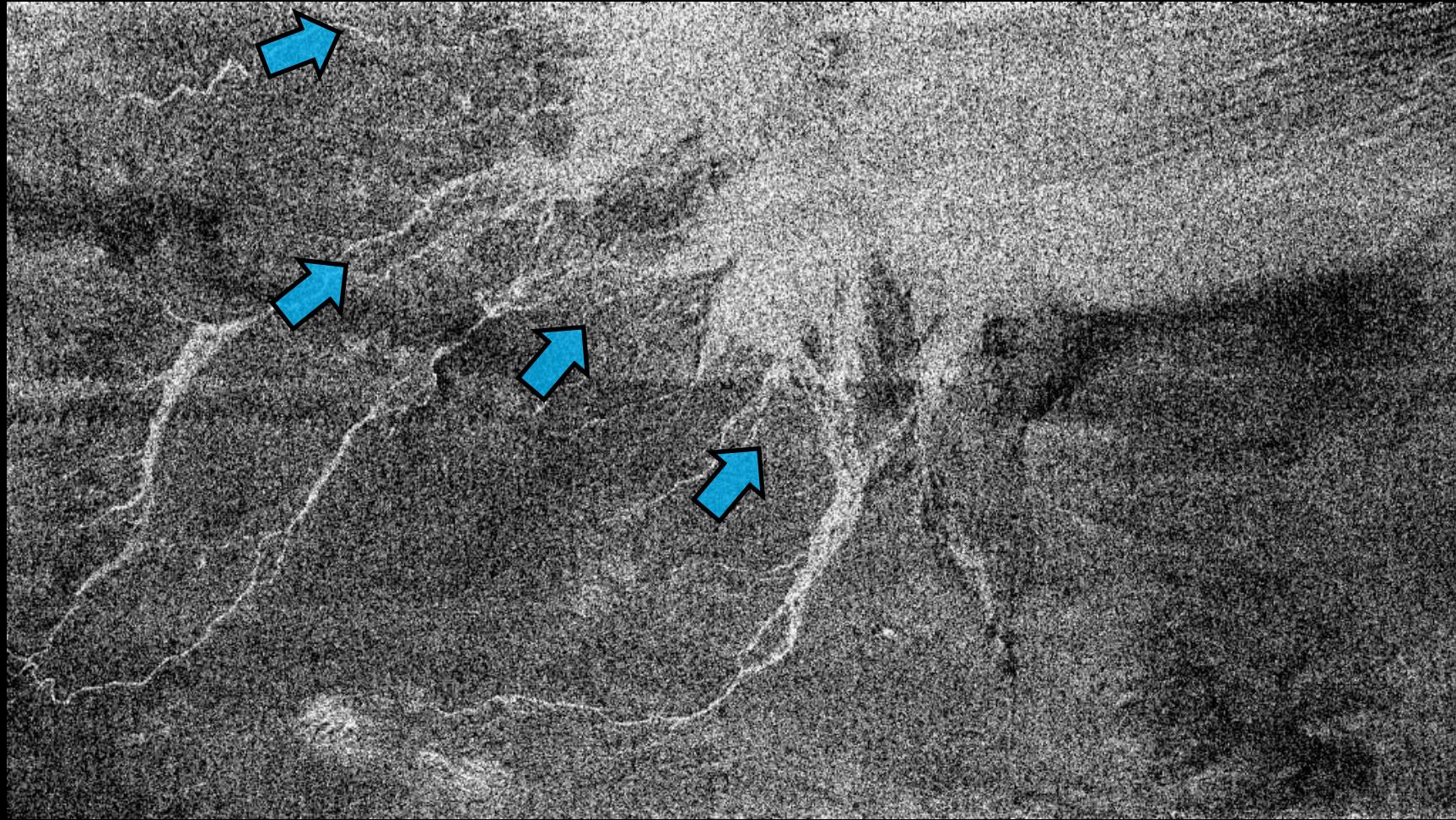
Ligeia Mare
[79°N, 248°W] **Titan**
100,000 km²

Contrast-enhanced T25 SAR Swath

Lake Superior, USA / Canada
[48°N, 88°W] **Earth**
82,400 km²

Channels on Titan

Anabranching channels deposit into a plain



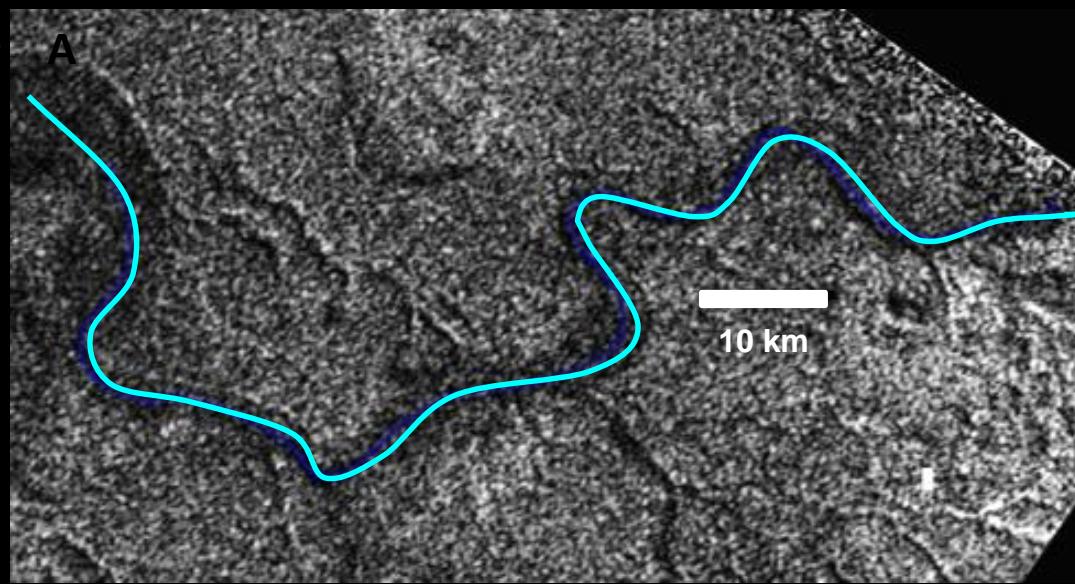
Elivagar Flumina, Titan [19.3°N, 78.5°W]

Contrast-adjusted Planetary Photojournal entry PIA07366: <http://photojournal.jpl.nasa.gov/catalog/PIA07366>
Image credits: NASA / JPL

Celadon Flumina and Mississippi River

Similar meander forms

Titan
Celadon Flumina,
Titan [-73°S, 29°W]

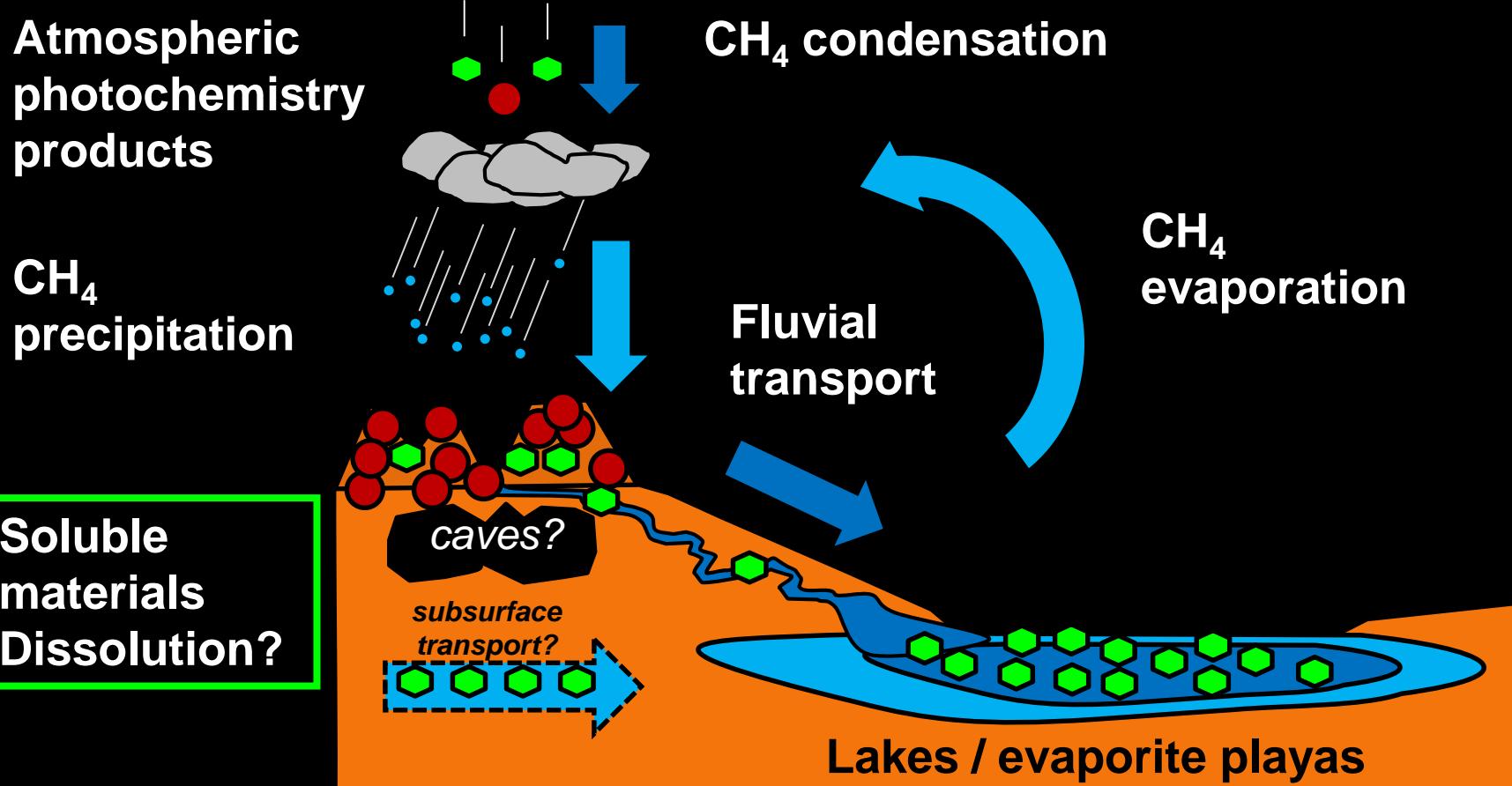
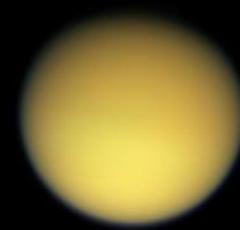


Earth
Mississippi River
Mayersville, MS
Earth [33.0°N, 91.1°W]
(Google Earth image)

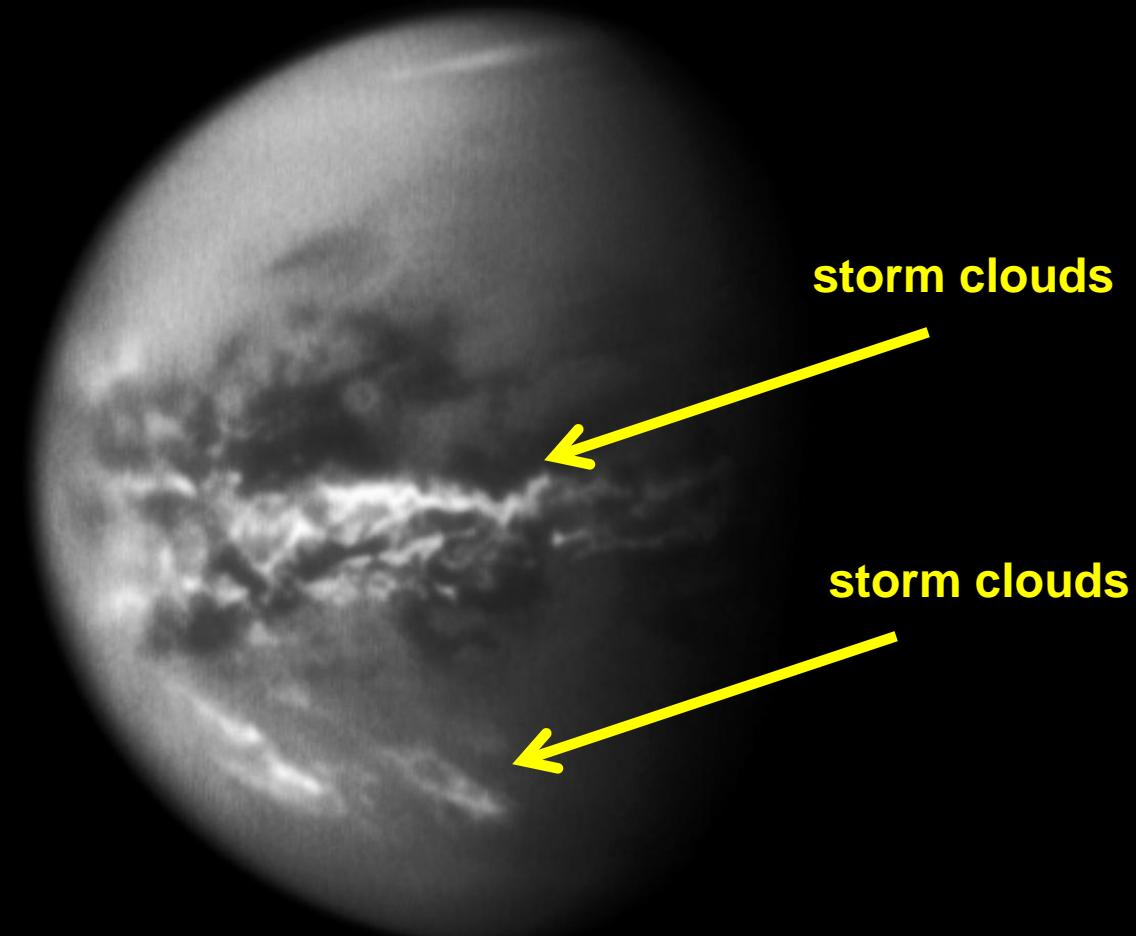


Titan Organic Cycle

Organics and CH₄



Titan storm outbreak

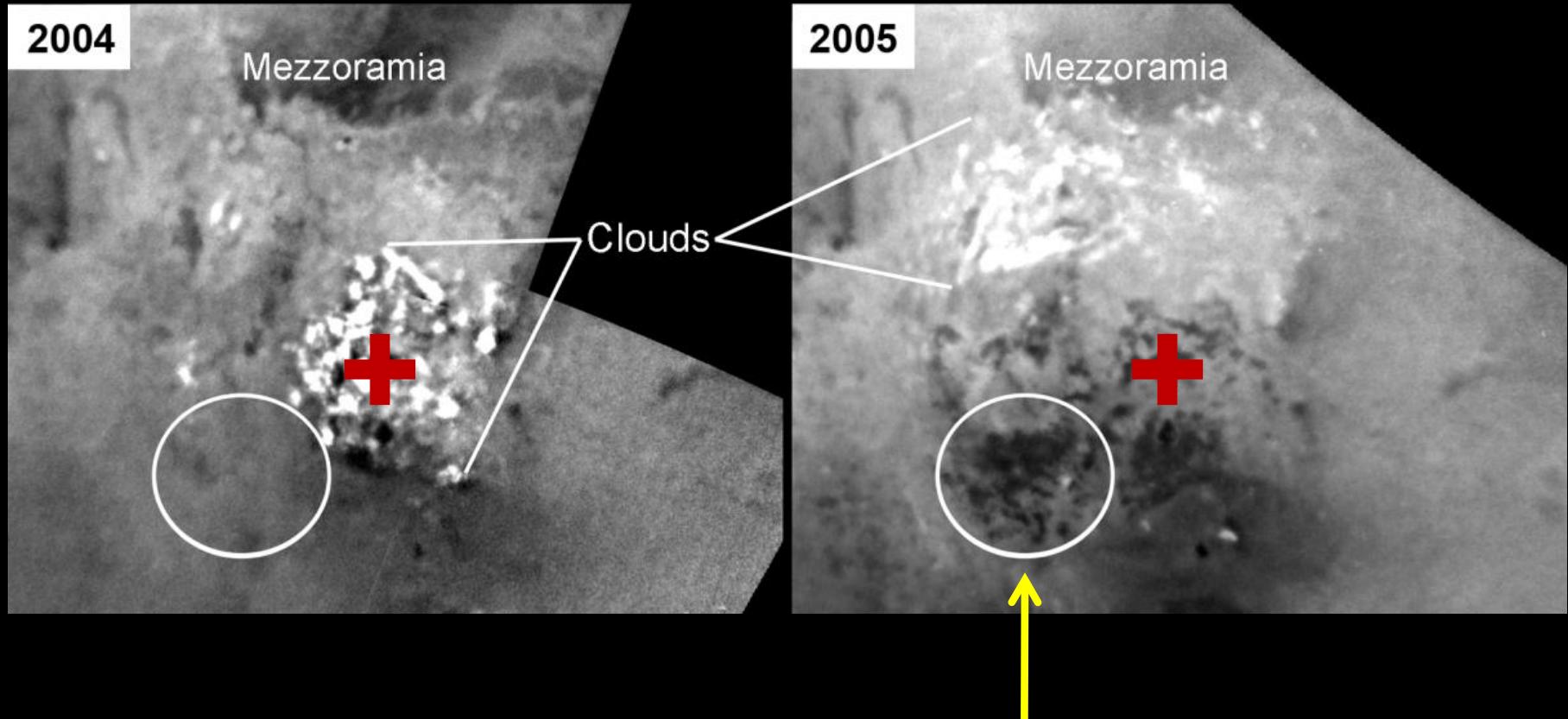


October 18, 2010

Image from Planetary Photojournal entry PIA12810: <http://photojournal.jpl.nasa.gov/catalog/PIA12810>
Image credits: NASA / JPL / Space Science Institute

Active rain cycle

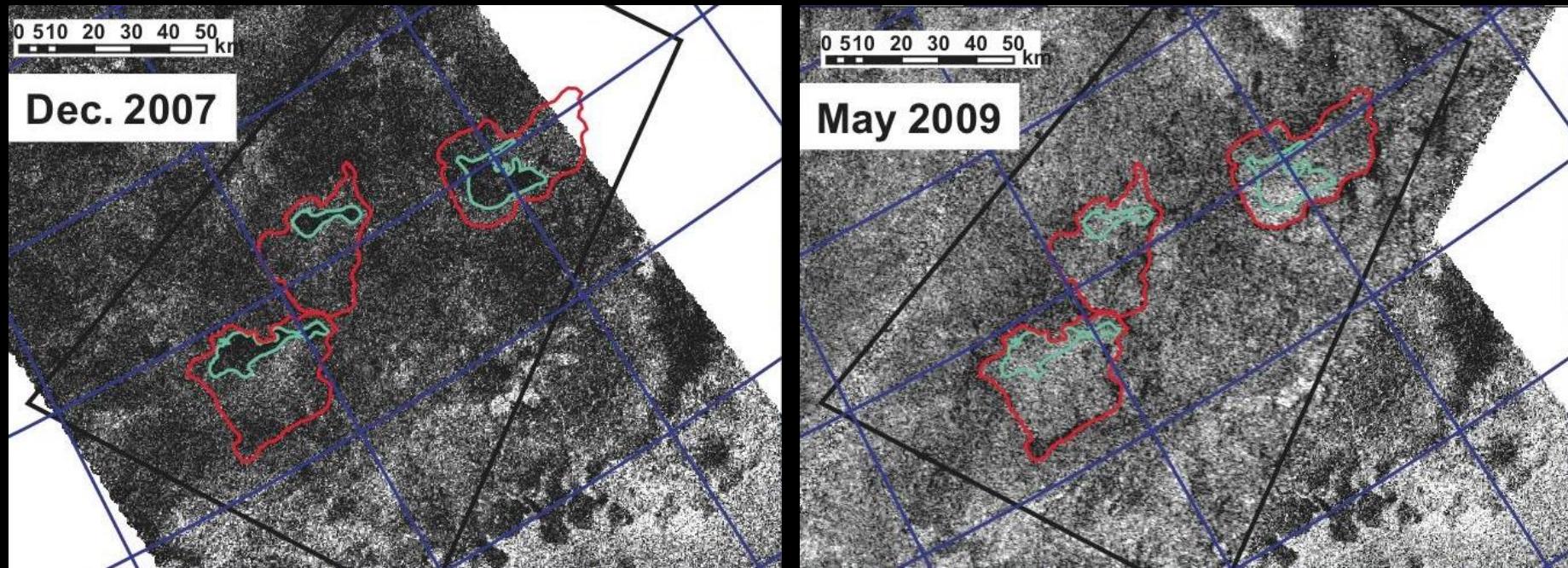
Rain-flooded playas



Planetary Photojournal entry PIA11147: <http://photojournal.jpl.nasa.gov/catalog/PIA11147>
Credit: NASA / JPL / Space Sciences Institute

Ref: Turtle et al., Geophys. Res. Lett. 36 (2009) L02204.

Drying out of South Polar Terrain



South Polar lakes appear to dry out

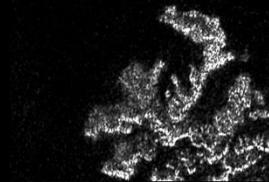
Planetary Photojournal entry PIA12281: <http://photojournal.jpl.nasa.gov/catalog/PIA12281>
Credit: NASA / JPL / Space Sciences Institute

Ref: Hayes et al., Icarus 211 (2011) 655-671.

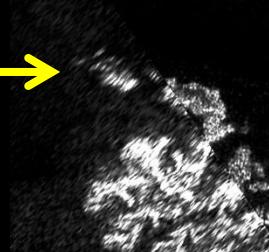
Titan's Magic Island?

Changing features in a Titan sea

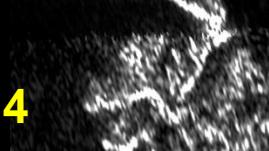
April 26, 2013



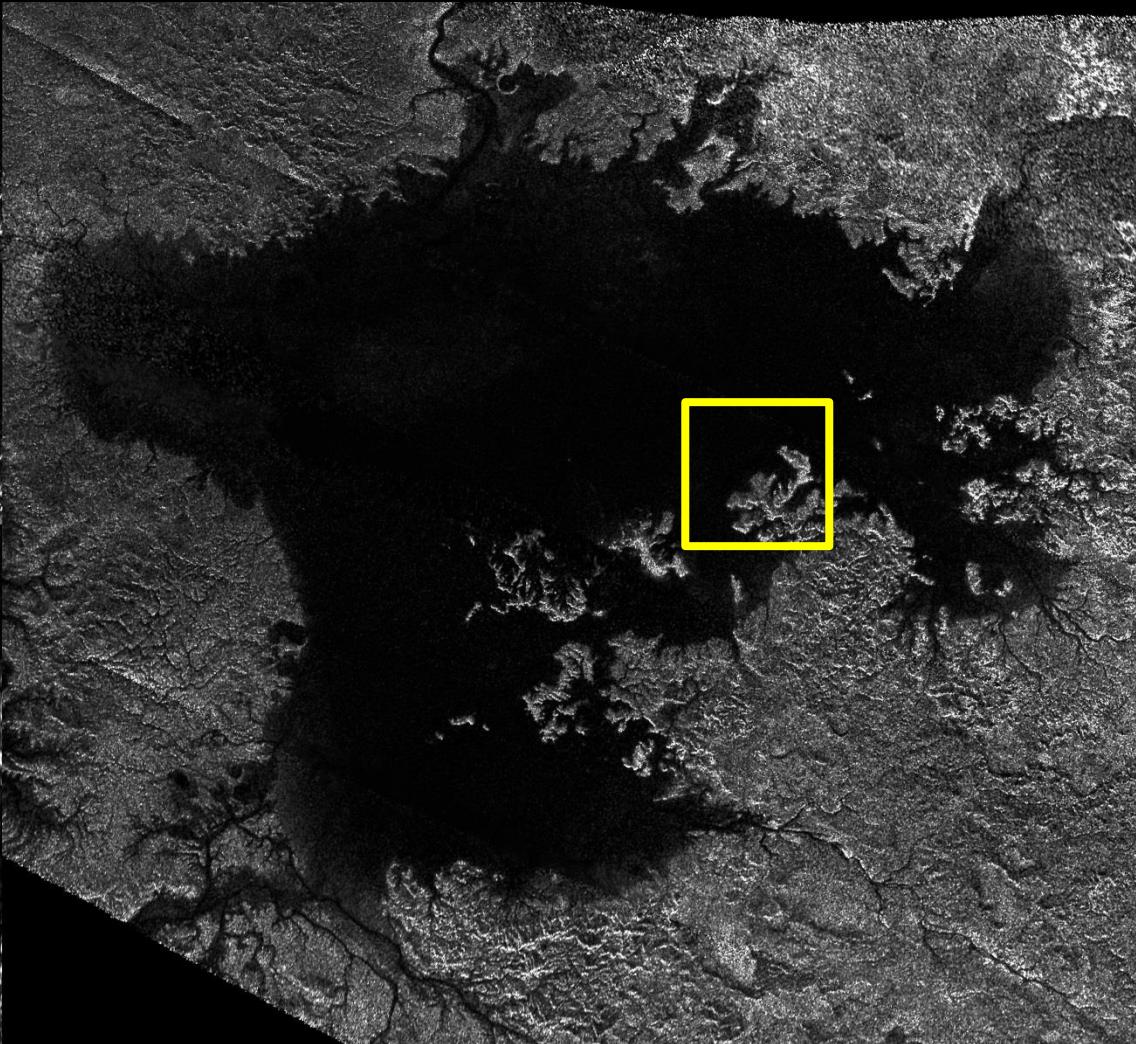
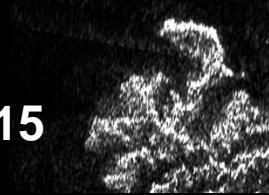
July 10, 2013



August 21, 2014



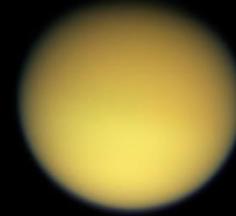
January 11, 2015



Reference: Hofgartner et al., Icarus, 2016.

Image Adapted from Planetary Photojournal image PIA18430 (NASA/JPL-Caltech/ASI/Cornell)

Fluids and materials



Earth (298 K)

H_2O

Fluids

Titan (95 K)

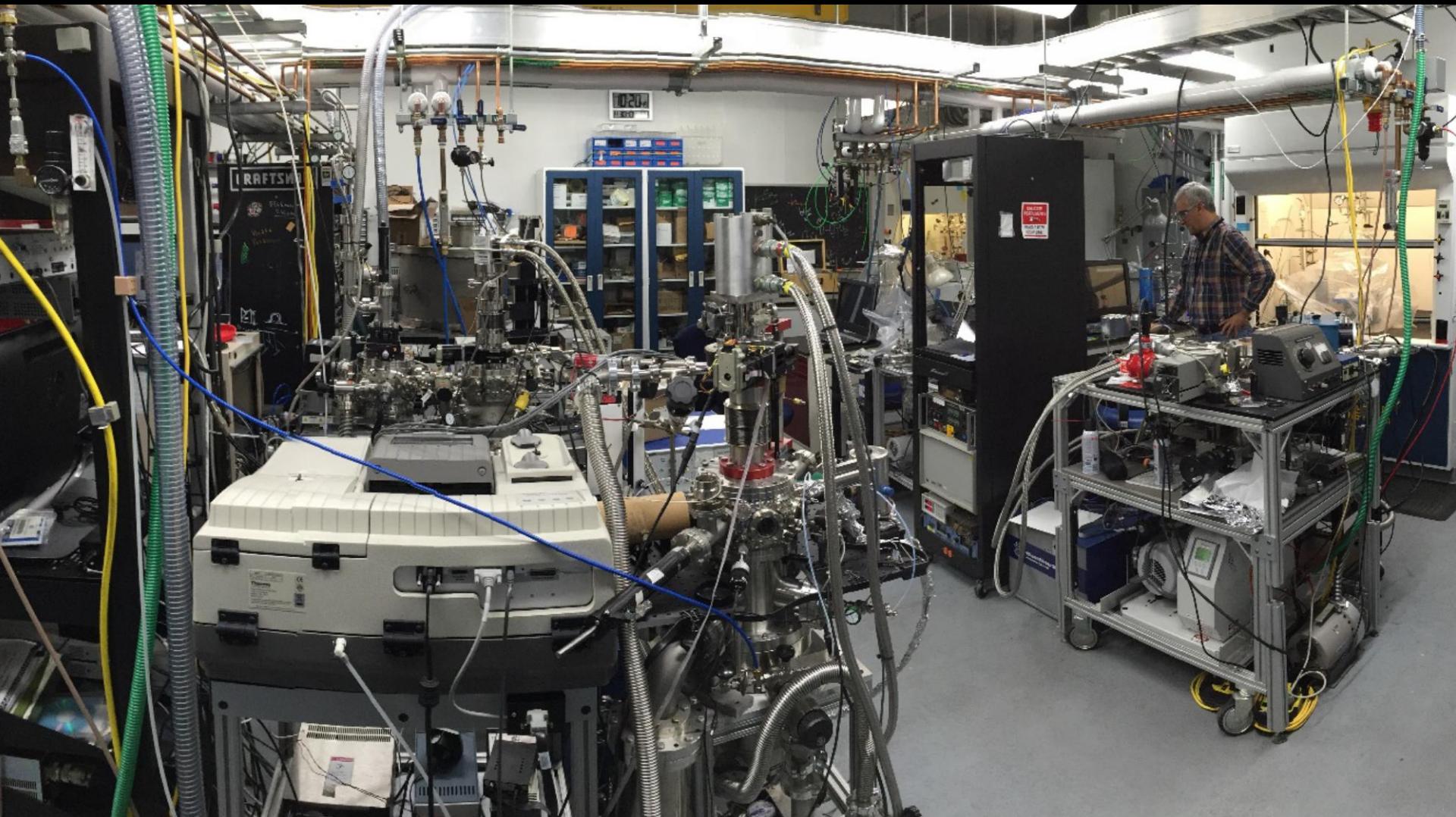
Methane (CH_4) / N_2
Ethane (C_2H_6)
Propane (C_3H_8)

Materials

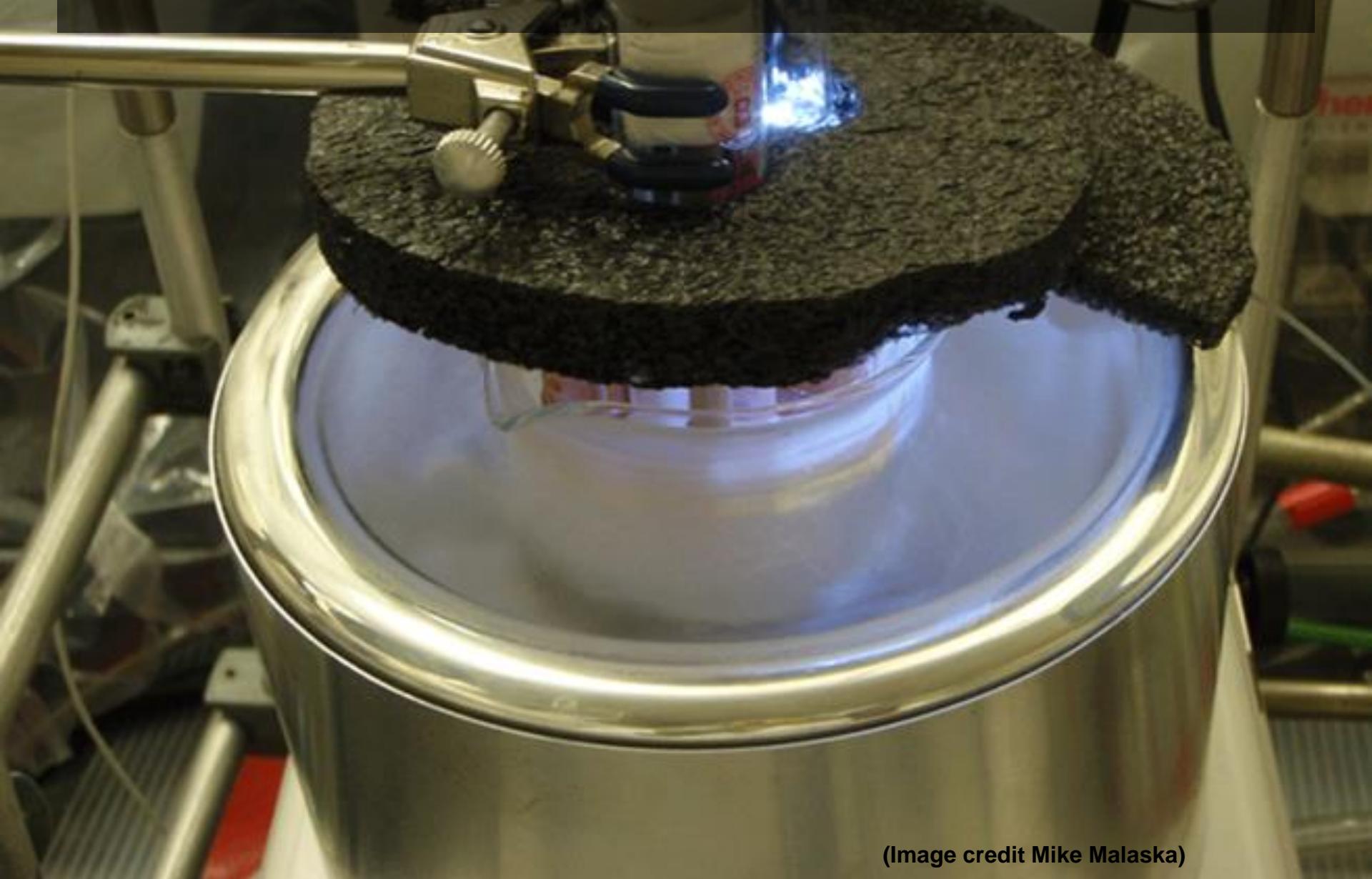
Halite (NaCl)
Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)
Limestone (CaCO_3)
Dolomite ($\text{CaMg}(\text{CO}_3)_2$)
Silica (SiO_2)_x

Acetylene (C_2H_2)
Ethylene (C_2H_4)
Hydrogen cyanide (HCN)
Acetonitrile (CH_3CN)
Acrylonitrile (CH_2CHCN)
Benzene (C_6H_6)
Cyanoacetylene (HCCCN)

JPL Cryogenic Chemistry Laboratory

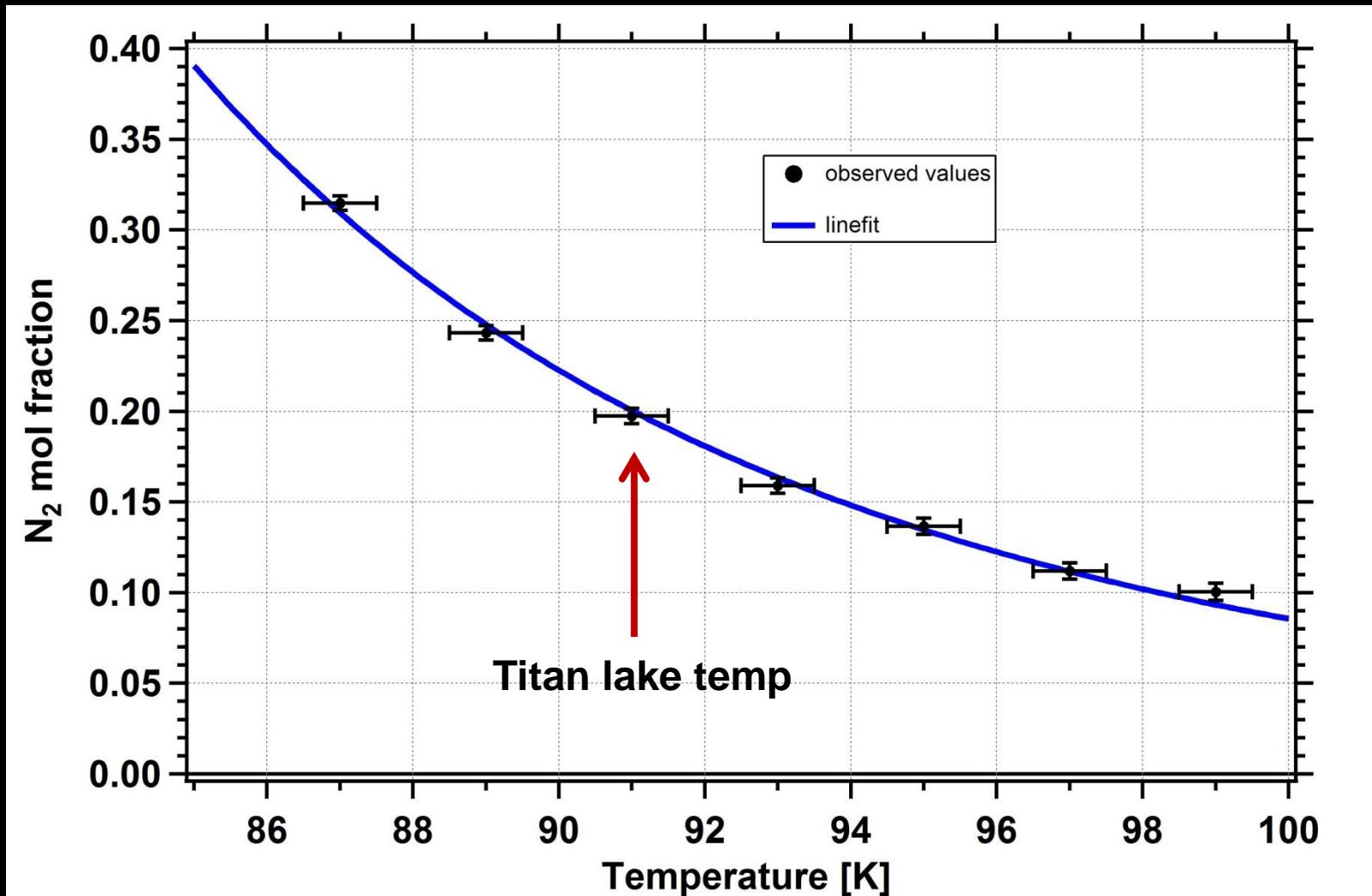


Laboratory simulation of Titan liquids



(Image credit Mike Malaska)

Titan lake weirdness N_2 absorption by cryogenic methane



Freezing ethane bubbles out nitrogen gas



16x actual speed

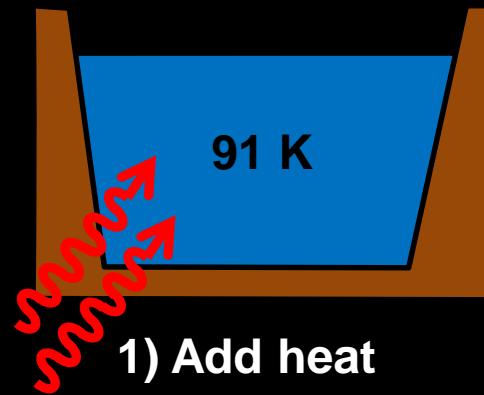
(IR fiber optic ATR probe)

Malaska et al., Icarus 289 (2017) 94-105.

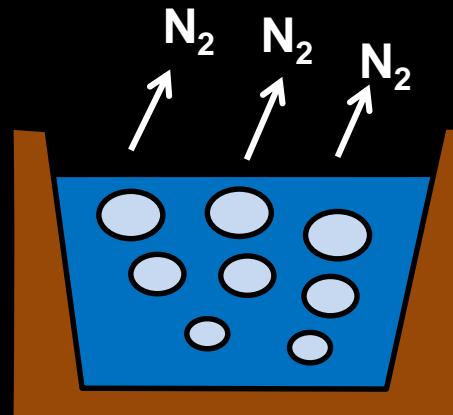
Link to video: <https://www.nasa.gov/feature/jpl/experiments-show-titan-lakes-may-fizz-with-nitrogen>

Implications (not like Earth)

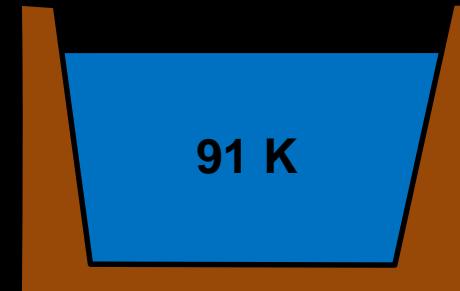
Lake fluids thermally buffered



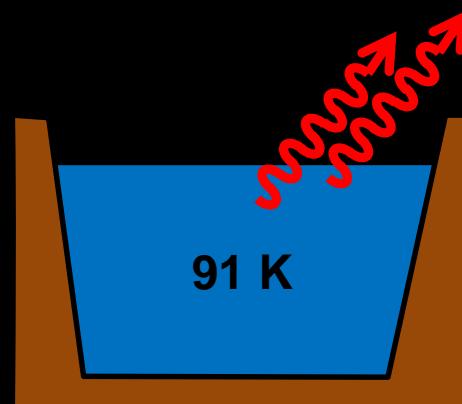
1) Add heat



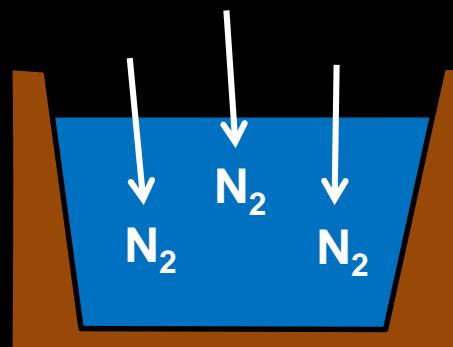
2) Nitrogen exsolves
Heat removed



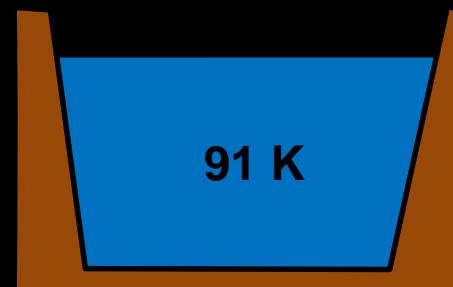
3) Buffered temperature!



1) Try to cool



2) Nitrogen absorbed
Heat released



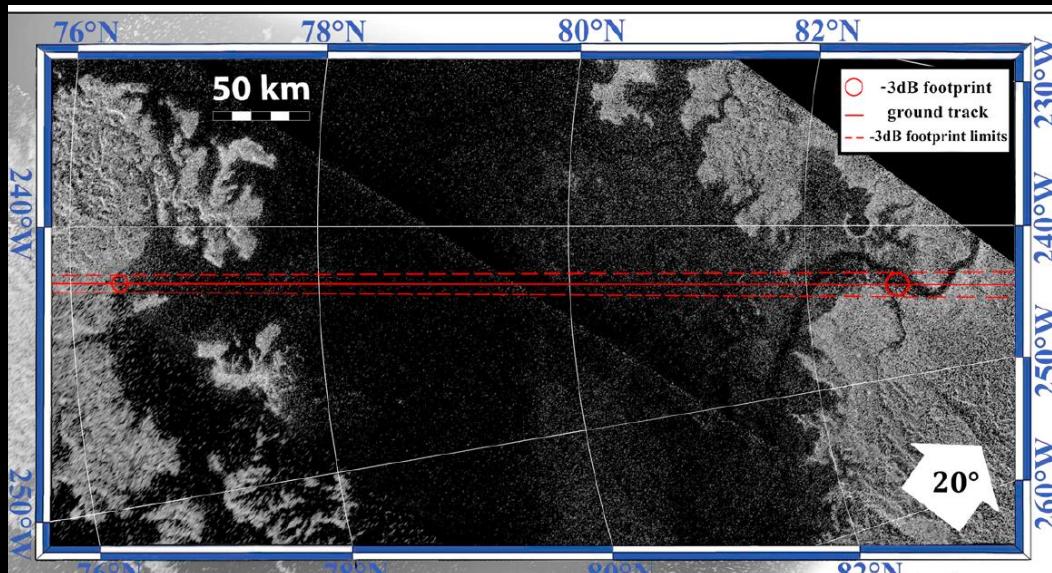
3) Buffered temperature!

Bathymetry of a Titan Lake

Low loss tangent constrains methane-rich composition

Cassini T91 Ligeia Mare transect

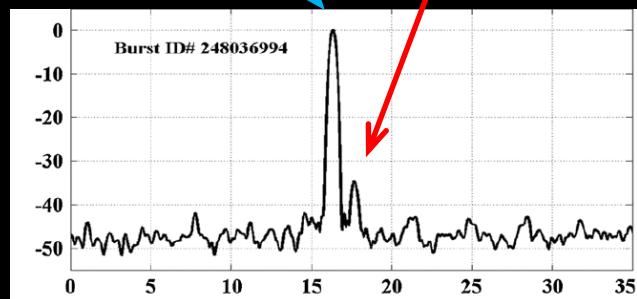
Low radar loss tangent
→ Mostly methane,
< 15% ethane in mix



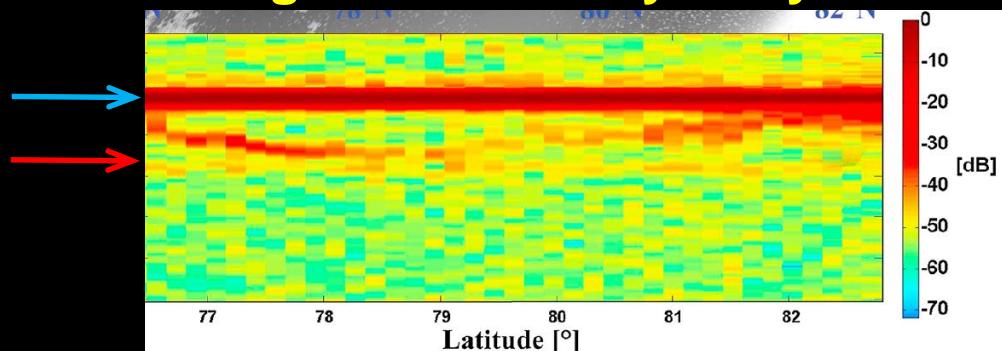
Cassini RADAR altimetry

Surface reflection

Bottom reflection



Derived Ligeia Mare bathymetry

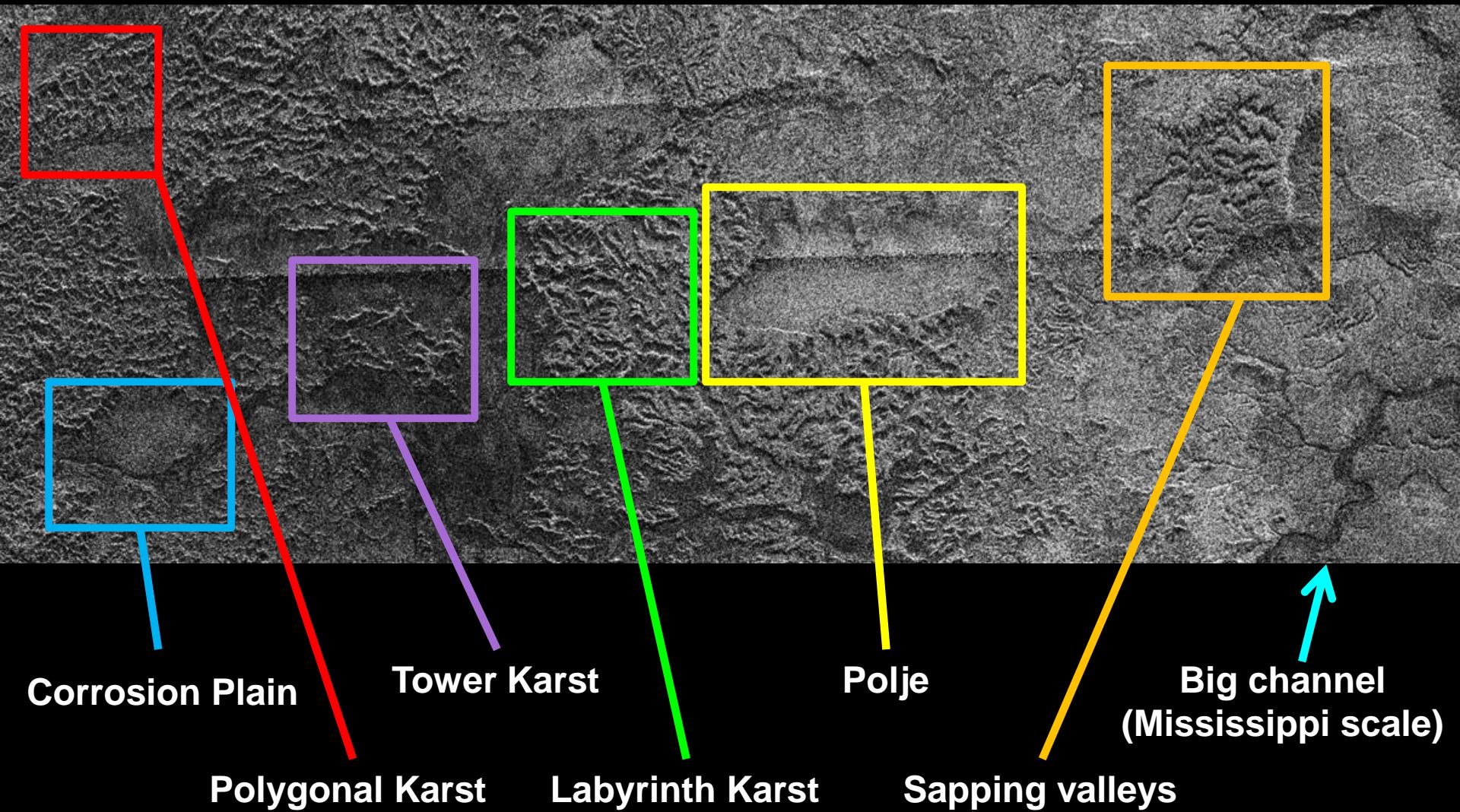


Mastrogiuseppe et al., Geophysical Research Letters 41 (2014) 1432-1437.

Mitchell et al., Geophysical Research Letters 42 (2015) 1340-1345.

Dissolving Titan

Sikun *Labyrinthus* karst-like terrains



Dissolution landscape development

Pitting → Sinkholes → Polygonal karst → Tower or cone karst

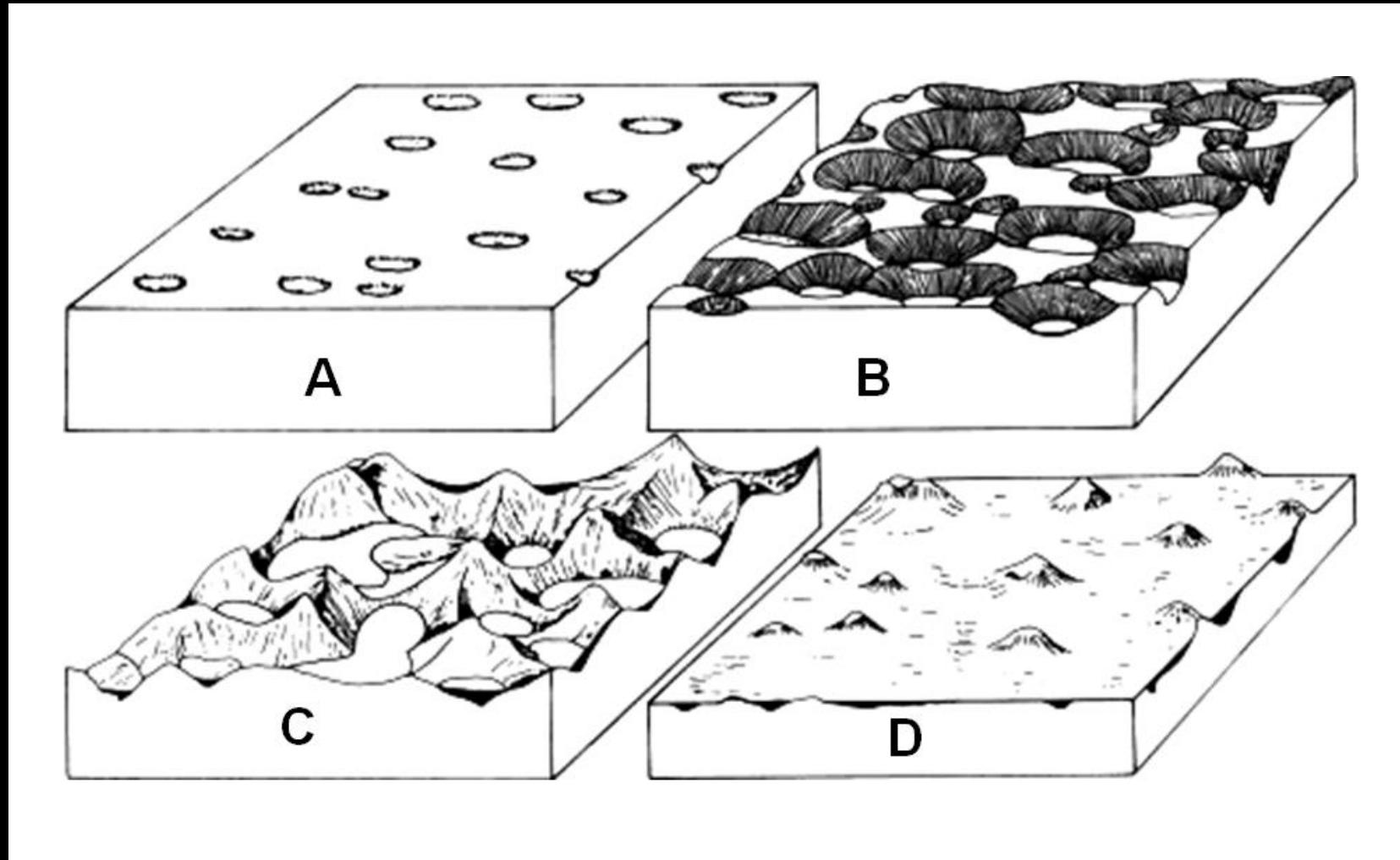
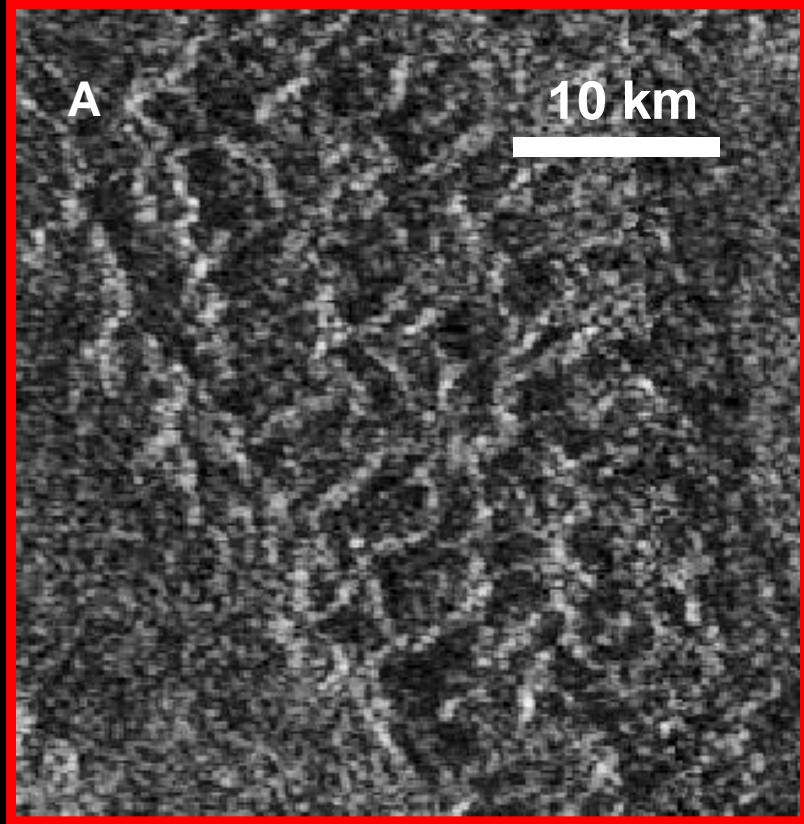


Figure from: Ford and Williams, Karst Hydrogeology and Geomorphology, 2007. Wiley. (Fig 9.63)

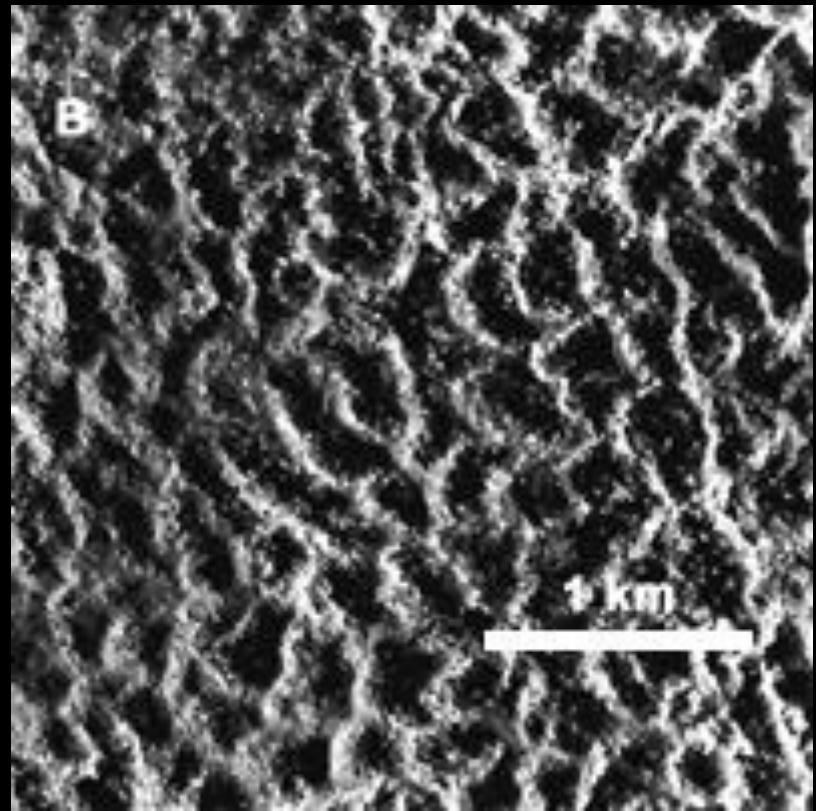
Polygonal Karst-like terrain

Closed valleys from dissolution

Structural control of valleys

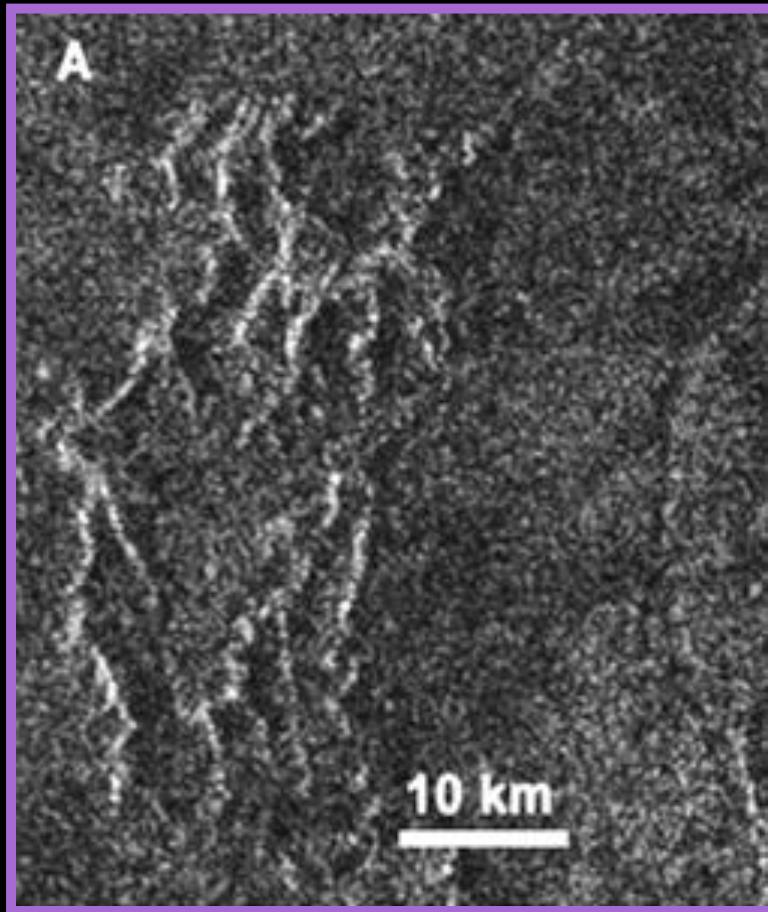


Polygonal Karst-like terrain,
Ecaz Labyrinth,
Titan [77.9°S , 28.9°W]

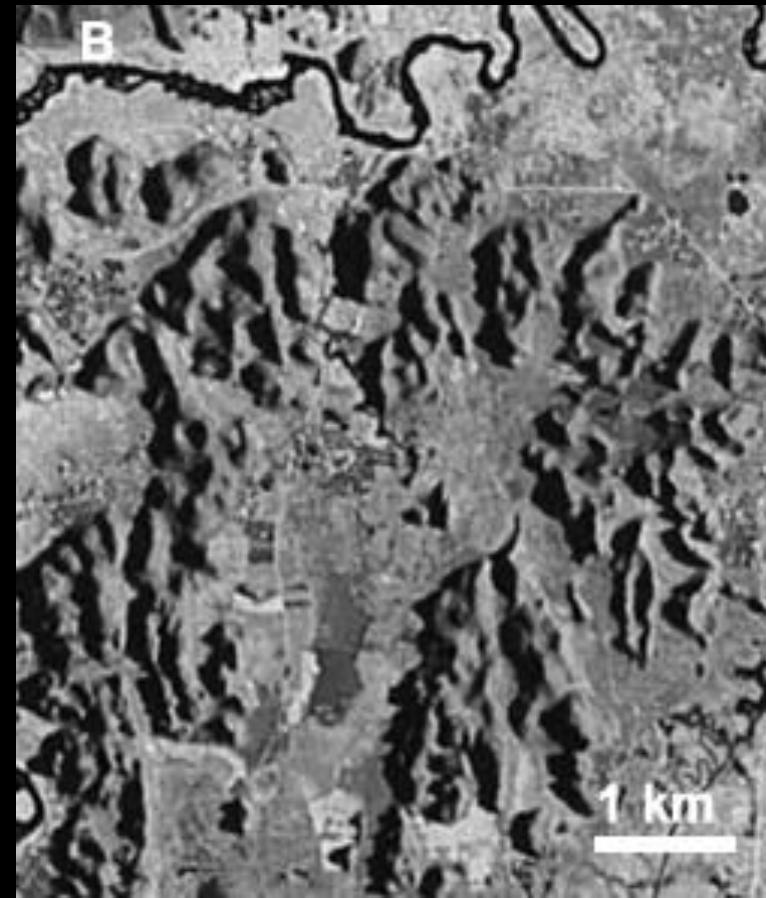


Polygonal Karst,
Darai Hills, Papua New Guinea,
Earth [6.8°S , 143.3°E]
(figure reproduced from [1])

Remnant Ridges (Tower Karst-like)



Tower Karst-like terrain,
Sikun Labyrinthus region,
Titan [77.9°S, 28.9°W]



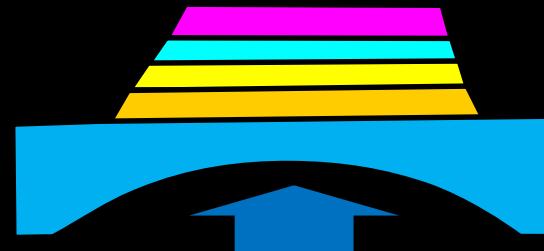
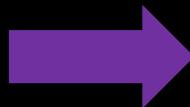
Tower Karst, Tanpaixiang,
Guangxi Province, China
Earth [23.4°N, 108.8°E]
(Google Earth image)

Labyrinth terrain evolution sequence

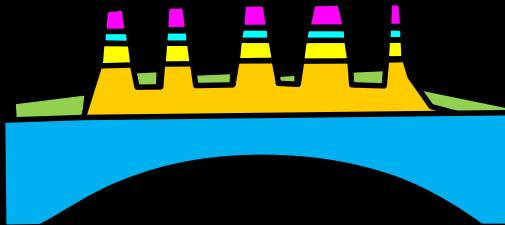
Sediments uplifted then eroded – Colorado Plateau style



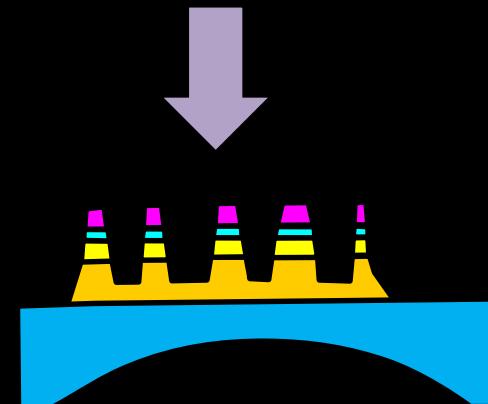
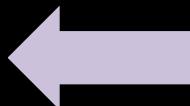
1. Basin sediments
lithified (evaporite?)



2. Uplift



4. Valley fill



3. Dissection (dissolution)

Titan Labyrinth Terrain analog?

Purnululu National Park, Western Australia

Devonian quartz sandstone eroding out to a surrounding sand plain

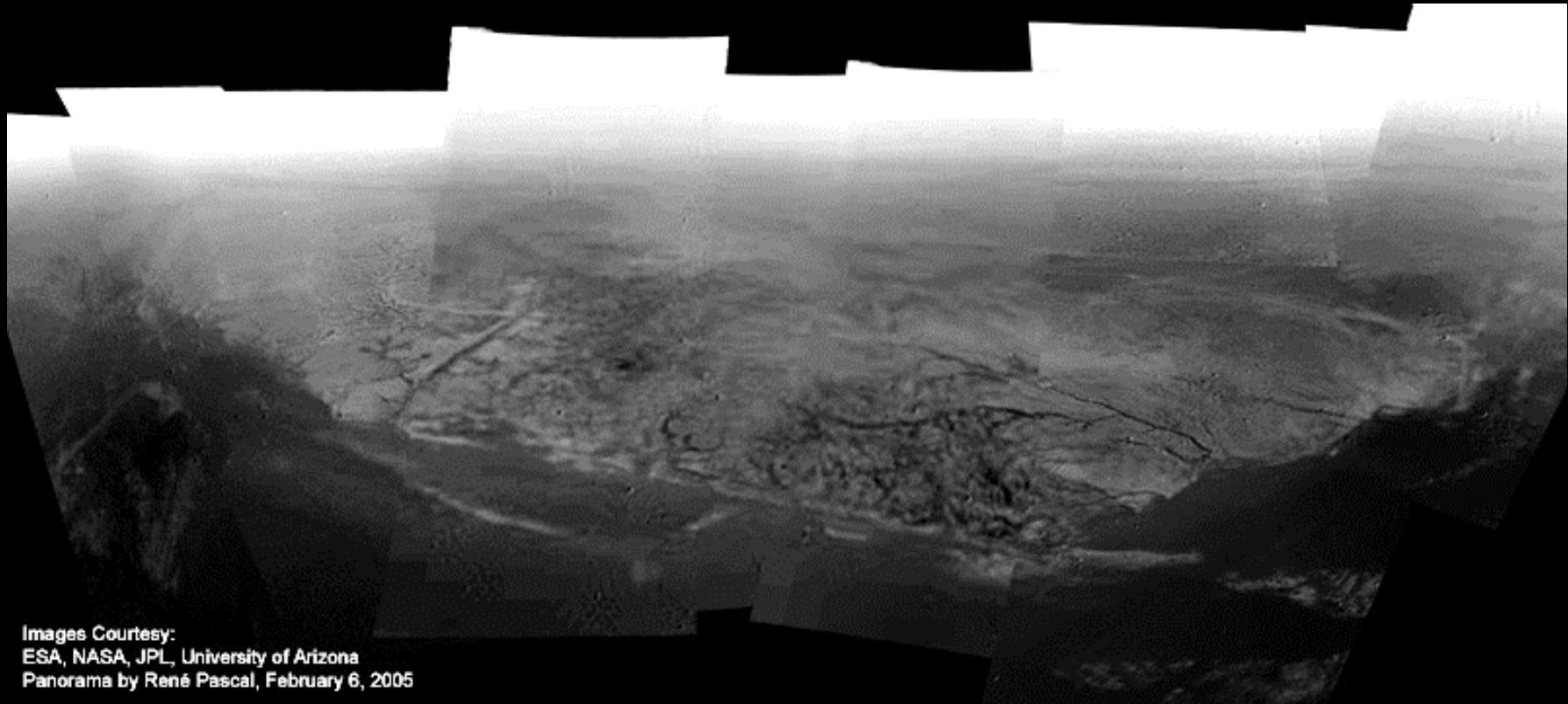
“the most outstanding example of cone karst in sandstones anywhere in the world” UNESCO



Huygens Probe descent to Titan

Huygens probe – January 14, 2005

Channels in bright terrain



Images Courtesy:

ESA, NASA, JPL, University of Arizona

Panorama by René Pascal, February 6, 2005

Titan Surface

Huygens Probe Landing Site

Rounded cobbles

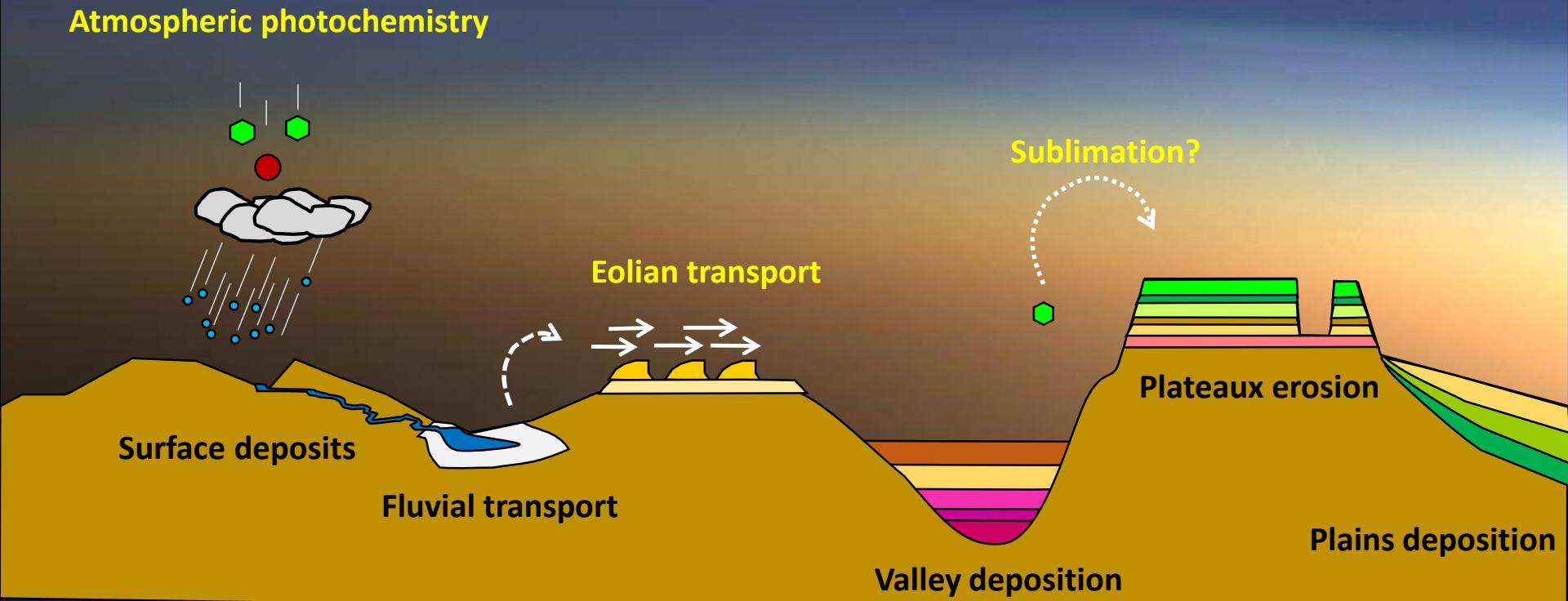
Sorted sizes

→ Outwash plain



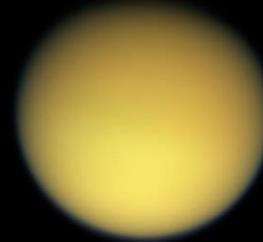
Titan Sediment Cycle

Like Earth, but different



"Titan is Earth without the drama"

Landscape scorecard



	Earth	Titan
Craters	few	few
Dunes	yes	yes
Mountains	yes	yes
Volcanoes	yes	Cryovolcanoes?
Clouds and storms	yes	yes
Lakes and rivers	yes	yes
Changing features	yes	yes

"Titan is the new Mars"

Future mission concepts

AVIATR Titan Airplane



Image credit: Mike Malaska

Dragonfly Titan drone



Image credit: APL / Michael Carroll

TAE Titan Balloon

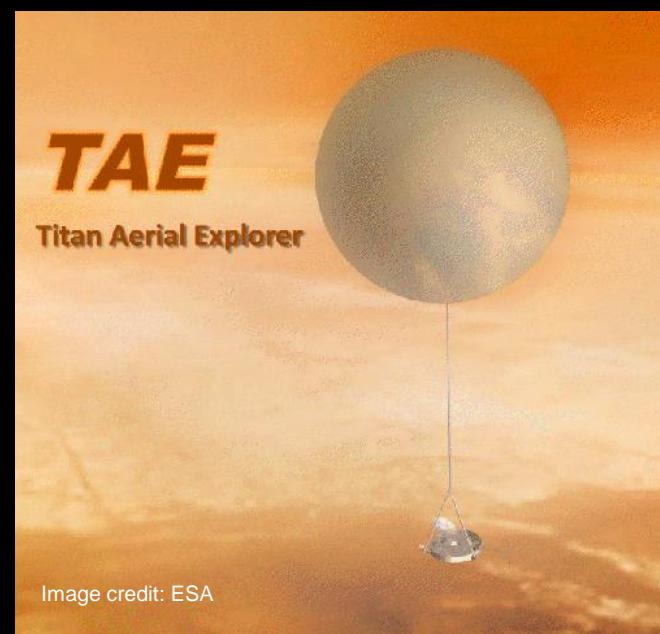


Image credit: ESA

Titan Mare Explorer (TiME)



Image credit: NASA

Titan and Earth studies

**Compare and contrast
two complex worlds**

- Atmospheric chemistry
- Haze formation
- Climate modeling
- Organic geology
- Prebiotic chemistry
- Ocean World astrobiology
- Future colonization